Managing Pile-Height through Image-Based Compensation in Digital Flexible Package Printing

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Abstract

Printing in flexible packaging is often done on very thin films whose thickness ranges from 12 micron to more than 100 microns. When the thickness of the printed ink layer approaches the thickness of the film, it often introduces severe roll distortion in normal roll-to-roll applications. This distortion is also observed in a less pronounced manner in applications that use stacking, such as labels and books. This distortion is conventionally managed by reducing the ink-pile height. In digital printing (inkjet and also in xerographic) the pile height problem limits the applicability of printing for flexible packaging applications.

In this paper we describe an imaging based for managing pile height that normalizes the surface height across the substrate. The solution proposed here tries to intelligently balance the ink-layer discrepancies across the roll width using image-based compensation so that cylindrical shape of roll is maintained. This enables the film/substrate to advance at a uniform rate, and the differential rolling stress across the substrate cross section to approach the normal operational range. This innovation will enable digital printing to play a more significant role in roll-to-roll based packaging applications such as flexible packaging.

Introduction and Background

Flexible packaging constitutes a large segment of the packaging market. In many applications of flexible packaging, printing is done on a variety of films whose thickness ranges from roughly 12 microns to hundreds of microns. For ease of handling, the films are supplied in rolls of various widths. To create a package, the film goes through a sequence of steps such as printing, lamination, cutting, sealing, etc. A preferred way to handle the film for many of these steps is to feed-in from a roll and output on a roll.

In roll-to-roll printing, the substrate is fed from an input roll to a printing device. The device prints a large number of repeat impressions of the desired graphics on the substrate, and output is fed on to a roll. Often the images are imposed a specific way to efficiently produce desired artifacts such as books, bags, labels or shrink-wraps. On the output roll, if the cumulative pile height of the printed ink is not relatively constant across the roll; one side of the output roll may become too tall while leaving an unmanageable slack on the other side. For example, if the graphics printed on the right side of the substrate contains substantial multicolored content, and the graphics printed on the left side of the substrate contains only one color or no graphics at all, the right side of the substrate will have a greater cumulative pile height and the output roll will have a larger circumference on the right than on the left side. In addition, the right side of the roll will be taut while the left side of the roll will have a lot of slack. When the same or similar graphics is repeatedly printed, as is typically the case with roll-to-roll printing, this repetition only magnifies the pile height problem at the output roll. Distortion in the output roll creates problems during the printing process and also during the downstream finishing processes.

This problem is acute for digital printing because the ink layer thickness of both direct marking and xerographic marking [1-2] is often larger than ink-layer thickness observed in conventional flexographic or lithographic or gravure printing.

The printing pile height in a Xerographic process depends on the size of the toner and technology used for dot-placement, registration, fusing temperature, pressure and surface porosity of the substrate. Typically toner particle sizes are in the range of 5 to 10 microns, and multiple different color toner layers are placed to achieve a desired color, thereby creating noticeable pile height problem. Figure 1 shows toner layer thickness in a high-end 4-color xerographic press.

Figure 1: *Cross section of a xerographic print. The toner layer is on top a coated paper substrate.*

Figure 2 shows a schematic of inkjet printing technology and its contribution to pile height. Inkjet drop sizes vary from a few picolitres to hundreds of picolitres. Each droplet then spreads over and flattens on the surface of the substrate. The extent of flattening depends on several factors including surface chemistry, porosity of the surface, viscosity of the ink and curing, fusing and drying process used. Obviously, larger the dot spread, smaller is the height of the ink layer. However, ink spreading adversely impacts the resolution and sharpness of the edges, thereby reducing the quality of the rendered image. Hence the ink designers try to control the drop spread to achieve the best results.

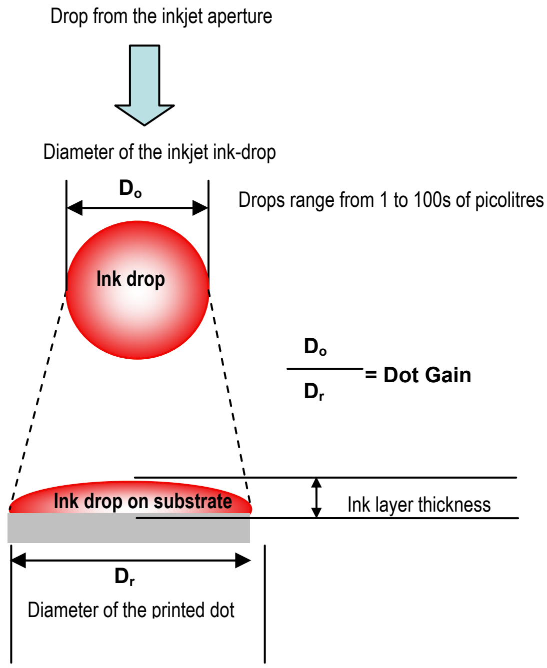

Figure 2: Inkjet dot gain and pile height.

Problems of Pile Height

As indicated in figures 1 and 2, current technology capability in digital printing often creates pile height problems.

1. The destination roll may suffer from wildly different diameters thereby making it very difficult to setup a productive continuous feed applications
2. Loading of the roll from one setup to the next; or from one workflow to the next becomes difficult
3. Film gets badly distorted in thin film applications (as in flexible packaging) and this also impacts the print quality.

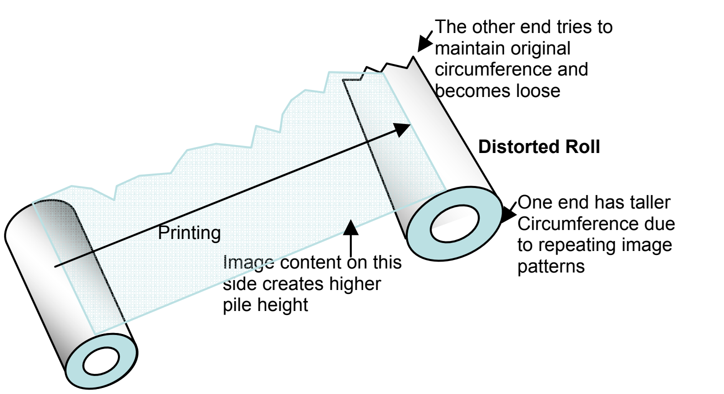

***Figure 3:** When image content introduces a pile height which is same order of magnitude as the substrate thickness (or larger) the printed substrate roll shows pronounced distortion for normal job sizes.*

Conventional Solutions to the Pile Height Problem

In flexographic printing newer thin pile height inks are being developed to meet the lower pile height requirements. These pile heights depend on applications. Industry typically achieves well below ten microns of ink layer thickness for thin film applications to tens of micron ink thickness for specialty printing applications [3].

There are also mechanical solutions where media handling kits are specifically made available for delivering media with higher pile height [4]

Neither of these solutions addresses the very high pile height of the digital printing process. More importantly personalized printing can create unpredictable change in pile heights that can make the problem worse. There are occasions where digital process can introduce an order-of-magnitude pile height differential. Moreover the conventional analog methods do not anticipate the dynamic change in print content. While it creates additional pile height problems, the capability to dynamically change the content is a key value proposition of digital printing.

Proposed Solutions

We propose a family of solutions to pile height problem. Our focus here is to make the pile height problem manageable by using primarily imaging methods. Essential parts of these solutions can be used in traditional printing. However these methods heavily rely on ability to dynamically change image at the print time. Hence these are uniquely designed to make digital printing acceptable to packaging and other continuous feed oriented applications.

The methods can be grouped into the following four categories.

- Imposition Adjustment
- Smart Image Adjustment
- Cumulative Pile Height Error Recovery
- Combination method

A common principle used here is to distribute the image thickness uniformly across the direction perpendicular to the feed direction either by rotation and translation of the image to be printed OR by adding new image artifacts in the waste areas of the roll. This enables the roll to put uniform tension across the film. Further to keep the roll nearly circular, we need to make image nearly uniform along the feed direction.

The basic premise of the first two methods (i.e. imposition adjustment and smart image adjustment) is that we can estimate the image pile height at any location on the image and it is generally constant w.r.to image pixel values at each color separation. Given an image vector at a pixel location or an image value for each color separation and given a printing process/system one could empirically determine the proportionality constant for pile height. One may design a pixel value to pile height transformation matrix or create a simple look-up table for pixel values and ink layer thickness.

The third category (i.e. cumulative pile height error recovery) however does not use ink layer thickness assumptions, but it leverages closed loop control of output roll of the printed substrate.

Here the height differentials on various points of the printed roll are measured and a corrective action is taken at the input side.

Finally the combination method simply uses the combination of all three principles to manage the pile height problem.

Imposition Adjustment solution

Traditional imposition principles are usually to minimize the waste and fit as many impositions as possible on a given size of the substrate and complexity of die for cutting or other finishing operations. For pile height management we add an additional constraint to keep the printed pile height uniform along and across the feed direction.

1. For each image to be imposed an estimated printed height profile is calculated.
2. Images are rotated and translated so that mean-square height differential is minimized in the direction perpendicular to the feed direction. This will allow film to be taught across its width
3. Along the feed direction depending on the width of the roll, two or more points are selected for minimizing the cumulative pile height. Two points (one on each edge) are selected for very narrow webs and more points are selected if the film is thin and if the web width is large.

Figure 4 shows a schematic of a film and what and where height variations need to be minimized.

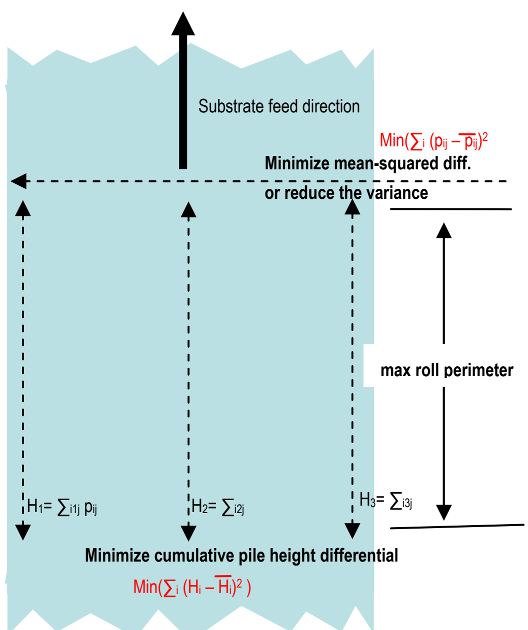

Figure 4: *Schematic that shows the algorithms for measuring the differential values that need to be measured to make the pile height problem manageable.*

This may become an over constrained problem and results achieved by this method may rely heavily on uniformity of pile height profile of the image itself. However this kind of minimization is essential because in large jobs even nearly uniform images can add-up to large differential pile heights. For smaller jobs it may be enough if just the cumulative pile height differential is minimized. (i.e. minimize along the feed direction in select points). Since the minimization is for cumulative value, there is larger freedom for imposition of images.

Smart Image Adjustment

The idea here is to add new images (usually lines and polygons) of known height profile to the film in the selected blank (graphics free) areas. The blank areas may be waste areas on the substrate or may be intentionally left for pile-height management. Depending on the profile of the image to be imposed, one can determine whether one can use naturally occurring waste areas after imposition or one has to create specially designed pile height management areas. One way to test that is to use the computation in the previous method and see the pile height differential values are above an empirically determined threshold.

Once the blank areas known, the smart imaging adjustment method simply adds new image patches that will be eliminated (cut out) during the finishing processes. These image areas are dynamically added at the print time. This enables not only adjustment for traditional unchanging images to be printed effectively, but also allows uniquely digital capability of personalized, customized content where imposition step is usually not possible or is uneconomical.

The height differential correction is done by adding new images such that cumulative image differential is minimized. This addition allows is to reduce height value H_i (see Figure 4) variations by adding image patches at selected spots. As the image information flows through the DFE, we dynamically calculate the cross sectional height differential and cumulative pile height differential and compute the new image patch to be added. The modified image is then used for printing on the film.

In other words, the input to the DFE is imposed images and the output from the DFE is a modified image that tries to keep the pile height constant.

Cumulative Pile Height Error recovery Solution (closed loop solution)

The idea here is to measure the pile height at several cross sections of the output roll during printing and using the information to add new image patches. In this method sensors are placed on the printed substrate roll and sensor values are used for changing the image pile height. A representative sketch is shown in Figure 5. The figure shows three sensors that measure local thickness of the roll. If the values returned by sensors are Ph_1, Ph_2, Ph_3, the image patch pile height at corresponding locations is set proportional to (1- normalized(Ph_1)), (1-normalized(Ph_2)) and (1-normalized(Ph_3)), and so on.

The normalization of sensor value can be made dynamic by using the maximum value of the three values to normalize, i.e.

$$\text{normalized}(Ph_i) = Ph_i/\max(Ph_1, Ph_2, Ph_3)$$

This method of normalization will help with minimizing the cost of image patch to be added. Image patches are added to waste or designated areas on a continuous basis; however the added pile height is made inversely proportional to the output pile height sensed.

Other option for normalization is to use a constant high value rather than maximum of the sensor values. The advantage of that normalization is it may quickly achieve balance in the roll, but it may not minimize the cost of added ink.

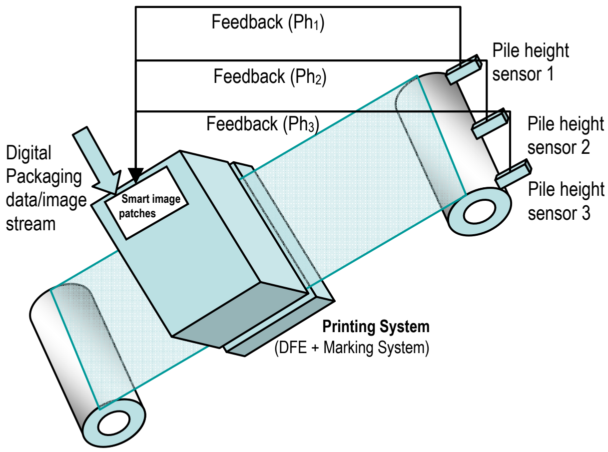

Figure 5: *The schematic that shows feedback mechanism for dynamically correcting the image by adding corrective image patches at the waste or designated locations.*

Combination Method

Depending on the application a variety of combinations of the elements of above three methods can be used for management of pile height.

Minimizing the Cost of Adding Image Patterns

Trivially it is possible to use highest pile height patches in a continuous form to obviate any image content based pile height variations. However it comes at a cost. Cost of ink is often the largest cost in printing, and maximum pile height can yield high ink cost unless special low cost ink is used just for balancing – that may have its own cost of setup and adverse side effects on print quality.

In the methods described here it is possible to use small image patterns that minimize the amount of ink needed, and using standard mathematical methods we can minimize the amount of ink used for pile-height management for the entire job rather than local minimization. The size of the corrective patch should be large enough to account for overlap errors across output roll revolutions. Similarly the distance between corrective patches should account for the diameter of the receiving roll. Larger the diameter, larger can be the inter-patch gap. Smaller the uncertainty of predicting the overlap accuracy across revolutions, smaller can be the patch size.

Summary

Pile height is a well known problem in printing. It becomes a critical issue in flexible package printing. Digital printing yields larger pile height than traditional flexographic, lithographic and gravure printing. The method described here allows us to manage digital printing by balancing the pile height across and along the feed direction of printed substrate. This method relies on ability to change graphics to be printed at the very last moment. This capability is unique to digital printing, and the method described here exploits that ability to do the pile height balancing while minimizing the cost.

Key idea proposed here is to control the imposition of the images and adding new image patches in the waste or designated areas to balance the pile height.

References

[1] E. Dalal "Method for forming a toner image with low toner pile height" US Patent Issued on March 20, 2001.

[2] R. Coleman, "Color order in predicting pile height constraints in a xerographic color printing system", US Patent Issued on May 19, 1998.

[3] Harper Inc. http://www.harperimage.com/anilox-specs-line.asp.

[4] Higher pile height delivery kit @ http://www.kba-usa.com/wtt?utm_source=wtt&utm_medium=banner&utm_content=textlink&utm_campaign=We%2BPrint%2BMoney.

Author Biography

Shriram Revankar received his Ph.D. in Computer Science from SUNY Buffalo (1993) and MS in Computer Engineering from IIT Madras (1987). Since then he has worked in the Research and Technology Division at Xerox in Webster, NY. His work focus has been in software applications and distributed systems areas.