High Throughput Industrial Digital Printing

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Abstract

Digital printing will be beneficial to the industrial printing market - labels & packaging, decorative printing - because lead times will be shorter, job lengths can be longer and there is the added benefit of fully variable data printing. A high throughput is needed and the output has to be similar to traditional printing while the substrates vary from very thin to very thick foils, films, aluminum and paper.

The development of UV curable jetting inks and robust grayscale IJ printheads make it possible to build an industrial digital multi-color press. To achieve the necessary throughput (currently 800 sq.m/hr) a single pass system is needed.

A single pass system has different requirements and specifications for the printheads, and requires specific tolerances in the assembly while the complete solution has to be efficient and economically optimized. The use of low viscosity UV ink drops in a raster has its own particularities. These requirements and the current solutions are discussed.

Introduction

Looking at the printing market, we can clearly distinguish 2 different worlds. The best known to people involved with digital printing is the document world. This one is steered by the look and feel of offset printing, and is driven by Letter and A3, A4 formats and duplex printing. The most common substrate is paper and the only function of the substrate is to carry the information. The second one, the so-called industrial printing world, is dominated by the established conventional printing techniques of lithography, flexography, gravure and screen printing. That world is "formatted" by big reels and higher speed. The substrates are seldom paper based and often have other functions than to carry the picture.

For digital printing for the document market there are solutions available e.g. electrophotography based solutions for large volume printing and ink jet for SOHO.

The existing digital industrial printing solutions are mostly ink jet based. Amongst these, one can define 2 segmentations:

1. The "wide format & multi-pass" segment.
2. The "high throughput" segment: This segment should offer a solution which not only provides high throughput but also meets the requirements of industrial printing. This is the segment where an innovative digital color press can play an important role.

Requirements

The industrial printing market is experiencing customer demands similar to other segments of the printing & publishing industries. Conventional printing doesn't meet existing and future needs of shorter runs, just in time delivery, environmental policies, and mass customization. Shorter lead times and shorter run lengths require often changeover of cylinders and flexo sleeves and decreased productivity of traditional presses and personnel. This together with the demand for test runs of larger jobs have created the need for a productive digital printing solution, making very short run lengths economically viable. Many industrial applications can benefit from the added value of variable data printing, in particular the security and packaging industries where the need for completely unique information is becoming obvious.

The requirements are similar to traditional printing regarding:

- Easy operation of the press
- Compatible with digital pre-press jobs and workflow on traditional press
- Variety of substrates: The substrates vary from very thin foils, films and paper over thick and thin aluminum to plastics. For labels these substrates are backed by a pressure sensitive adhesive and the finishing varies per application.
- High color accuracy, light stability and sufficient color gamut
- High rub fastness and adhesion
- Prints should be compatible with post-treatments (e.g. heat sealing, UHT process)
- Print quality

The digital press should have these additional advantages:

- Fast setup and job change-over
- Low down time and automated maintenance
- Longer job lengths and any repetition length
- Lower print cost for short run lengths
- Automated color management
- Variable data printing
- In-print on pre-printed stock

The substrate width ranges from 15 to 63cm and the printing speed should be at least 15m/min.

Ink

Conventional printing uses aqueous, solvent based or UV curable pigmented inks. Similar inks can be jetted by some ink jet printheads although the viscosity needs to be much lower. The high throughput is not obvious to achieve with scanning printheads but the above requirements can be met by a **S**ingle **P**ass **I**nkjet **C**olor **E**ngine.

The contradicting requirements of high speed drying and long open time in the nozzles to achieve the required productivity, are currently difficult to meet with aqueous inks. UV curable jetting inks are the better choice for many industrial printing applications[1]. UV curable inks adhere very good to a wide range of substrates. They have a high rub resistance, scratch fastness and water fastness. UV curable inks can be formulated without volatile organic compounds. Because of these arguments and more especially for environmental reasons there is a general breakthrough of UV inks in the industry. Due to the inherently low viscosity (~10cPs at operating temperature), the jetting inks are different compared to screen, flexo and gravure inks.

UV curable jetting inks are a significant challenge to the ink formulator. The jetting behavior of tiny ink droplets is sensitive to local variations in the ink composition. The reliability depends on the homogeneity of the fluid, on achieving a stable micro-rheological behavior and on the behavior of the ink under acceleration[2]. A small particle size, filtration, dispersion stability and the absence of non-soluble contamination are extremely important.

A UV-curing unit hardens the ink immediately after printing. The extra cost of a UV-curing unit makes UV jetting ink less interesting for the wide format applications with scanning printheads, but for high throughput systems the curing unit compares favorably to the dryers needed with other ink types. The substrate might be subject to high temperatures during curing. Many solutions e.g. water cooled counter rollers or cold mirror lamps can be installed to deal with this. As this (well controlled) curing is the only part of the printing process where heat is involved, this means that heat sensitive substrates such as thin foils or self-adhesive paper can be printed. Due to the inherent low viscosity of the jetting ink, there is oxygen inhibition affecting mostly the surface cure. More than one type of photoinitiator is used in the inks and there is the potential benefit of nitrogen blanketing and/or the use of more UV lamps with different spectra. Depending on the requirements of the application, the flow rate of nitrogen and the number and output power of the UV lamps can be optimized against the amount of photoinitiator in the ink. At very low oxygen levels, direct ionization is possible and no photoinitiator is needed: the UV-C does the polymerization by direct excitation of the double C=C bond. Other more appropriate curing systems can be applied to fit the most severe curing requirements.

Tests by industrial users have proven that the currently used inks stand well the industrial finishing (tolerating higher finishing temperatures up to 230 °C). The color fastness and the scratch resistance are very high and the adhesion is very good for many substrates. The system enables fast printing and drying. The combination UV curable inks and Drop-on-Demand ink jet make sure there is no ink waste and no ink recycling. The industry acceptance is becoming a fact for UV curable inks and will become a fact for UV ink jet.

The developments over the last two years clearly show that a lot of the ink restrictions can be solved by the ink providers, most of them having different skills for different applications and substrates.

The short time between jetting and curing, the ink dots are low viscosity drops positioned in a matrix with some overlap. On non-absorbing surfaces (coatings or substrates), there is risk for mottle: the chaotic coalescence of ink drops. This depends on :

- the wetting of the substrate: surface tension difference, local variations with dimensions similar to the dot size.
- time and therefor the printing speed
- viscosity of the ink
- cross-linking and chemical interaction

As long as a low viscosity of 10cPs is needed for printhead operation, mottle might occur on certain substrates and a simple, thin coating will solve this problems. On many substrates this is not necessary.

Printhead and Cartridge

Reliability

The initial investment for the industrial user of the digital press should be acceptable for the potential productivity and the operating costs should be low, and therefor these requirements are similar for the printhead or cartridge.

Thanks to the single pass concept, high printing speeds can be obtained. The printheads are not moving and the substrate is presented under the web. In a single pass system it is not possible to hide misfiring nozzles by using multiple passes (with an offset). Multiple heads are used to achieve the required printing width and number of colors, and these are kept continuously in prime condition with a fully automated maintenance system. Preventive maintenance is done every few hours and possible misfiring or nozzle failing is detected by a vision system. The cartridge frame is raised and a moving cleaning unit passes under the nozzles and cleans them by purging and vacuum suction, without touching the nozzle but well restoring the prime condition of the meniscus and cleaning the nozzle plate[3].

If a nozzle fails and can not be recovered by the automated maintenance system, the printhead or cartridge has to be replaced or refurbished. Nozzle failure is most often due to clogging caused by contaminates into the ink channels. These contaminates can be dust particles that got into the printhead during manufacturing, particles that pass through the ink filter or adhesives in the printhead that interact with ink chemistries. If clogging does not occur, lifetime of the printhead will depend on nozzle erosion or PZT fatigue. The nozzle lifetime can thus be described statistically. Increasing the lifetime means a more expensive printhead and a higher initial investment for the press buyer. The cartridge can be viewed as a consumable and is optimal when the cost of the cartridge per liter of ink, is sufficiently low compared to the ink price and the exchange of cartridges has negligible effect on productivity.

The above means that there is also an optimal width or number of nozzles per cartridge (equally for the printhead manufacturer) and this is currently not page wide.

Cartridge System and Color Bar

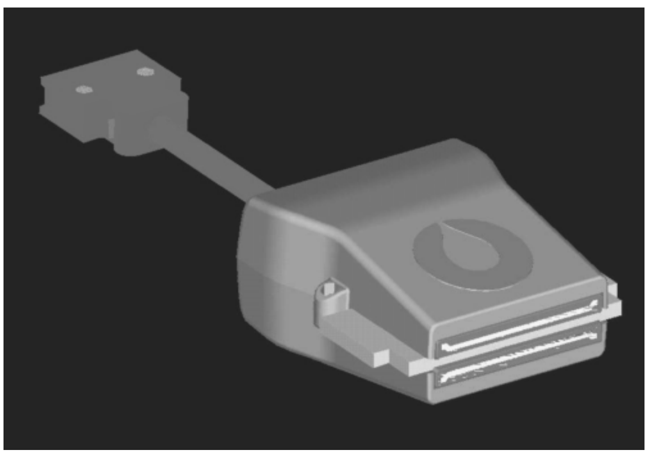

Figure 1. Cartridge

The current printhead has a printing width of 53.5 mm and 318 nozzles. A cartridge consisting of 2 printheads was designed that allows for easy set-up, maintenance, and replacement. The ink jet heads are mounted back-to-back, tightly assembled within highly accurate self-positioning brackets. The individual heads in the cartridge are offset by half a channel spacing, and the nozzle density is 636 nozzles in 2.11inch = 300dpi. The cartridges are featured with ink manifolds, ink-level sensor and steering-, and calibration electronics. To enable easy change over, the cartridges are equipped with quick connections for vacuum, pressured air, temperature control (cooling and heating), electronic-, and data connection.

The cartridge can be seen as the basic unit on a modular color bar where the cartridges are positioned in a staggered configuration, so that a populated color bar covers the web width with a 300dpi nozzle density, printing a single color. The color bar is the basic element in the modular SPICE design. Thanks to this concept the digital engine can be tailored to the customers need: by increasing the number of cartridges on a color-bar, the printing width can be increased; by increasing the number of color bars, the number of printing colors can be extended.

Grayscale

The Modulation Transfer Function states that the resolution is inversely proportional to the dot size. The dot diameter depends on the ink/substrate interaction and the drop volume. With a smaller drop, a higher resolution can be achieved.

Since the dots need to be slightly overlapping for a full coverage high optical density image, either a high nozzle density is needed in binary operation or grayscale operation can be used with variable drop size. The higher nozzle density has as main drawbacks: a higher cost and a large footprint, both caused by the large number of nozzles and piezo actuators needed.[4] The large footprint is a drawback for multiple color printing since the deviation in color registration with non impact printing depends on the distance between the first and last color (see below). The advantage of high nozzle density binary solution is the higher maximum speed which might outweigh the disadvantages for some single color applications.

The Xaar grayscale technology is based on their shear mode shared wall actuator and achieves grayscale printing by firing in rapid succession multiple droplets which merge to form dots of variable size[5]. The shared wall has a high channel density at the expense of a slower printing speed. The resulting footprint is small and a full color matrix of ink jet heads has sufficient speed (24m/min) and is compact enough to achieve the necessary registration accuracy.

The printheads print 7 different levels of drop volume ranging from 6 to 42 pL and the channel density is 150 dpi. The 42pl dropvolume is optimal for 300dpi, and two printheads have to be interleaved in a single pass system. The resulting resolution is higher than 300dpi, thanks to the grayscale operation with 7 different drop sizes.

It is a big advantage if the printing device itself can produce different densities, by varying the drop volume. This way, the screening no longer needs to bridge the gap from 0% to 100% ink by adding more or less pixels. It only needs to provide a smooth transition between two successive gray levels of the printing device. Combining these different intensities (gray levels) with a stochastic screening results in doubling the visual resolution and the apparent print quality, and this not only for continuous tone images but also for very small text.

Figure 2. Grayscale versus binary on text (magnified)

As a rule of thumb: 300dpi with 7 droplets equals 300dpi * √7 = 800dpi binary , after screening.

Dimensional Precision

Since it is not possible to hide misplaced drops or misfiring nozzles, there are stringent requirements on the position of each nozzle and on the firing angle of each nozzle.

The visual perception of deviation in dot placement from a perfect raster, depends on the viewing distance and the image. The perception is very sensitive for the relative displacement of a line in a grating. The misplacement of one line in a grating gives a contrast variation that depends on:

- the spatial frequency (line distance - type of image),
- the pedestal contrast
- the optical density profile of the line

From the contrast discrimination function,[6] it is possible to deduct that the variation should be less than 9µm at nearby viewing distances.

Besides the contrast variation, there is a phenomenon called 'hyperacuity' that allows the visual system to detect location deviations that are much smaller than the normal acuity of 1 cycle/degree suggests. The perception threshold for the variation in distance between parallel lines is 10 arc-sec. This corresponds to 10µm for a 20cm viewing distance.

The position of the dots should be accurate within 10µm. This means that the error caused by the firing angle and nozzle position accuracy should be less than 10µm. The nozzle position accuracy depends on:

- the nozzle to nozzle distance,
- the interleaving accuracy in the cartridge
- the deviation of first to last nozzle distance between printheads
- the accuracy of the nozzle position versus the cartridge mechanical reference
- the accuracy of the cartridge position version the color bar
- the thermal expansion.

Some of these requirements are not needed for a scanning system. Precise manufacturing of the printhead and automated optical alignment assisted by a vision system, make it possible to manufacture and align cartridges and color bars with the necessary accuracy. Cartridges can be exchanged without any further alignment.

To alleviate the accuracy requirements of the cartridge references and the color bar, stitching is used with overlapping cartridges. The overlap is only some nozzles and the stitching is perfectly managed both in software and/or hardware.

The thermal expansion is also important along the web because it defines the achievable color registration with non-impact printing. For color registration the dot position deviation should be less than 25µm, which becomes difficult to achieve if the footprint of the cartridge is too large.

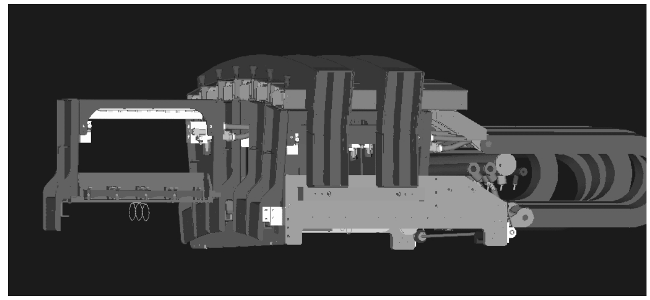

Figure 3. Color bar in position to exchange cartridge

Future Developments

Research efforts in the ink jet and ink industry will shift, thanks to the volume requirements of industrial printing. PZT printhead technology and manufacturing will become robust and the problems of integrating many heads reliably into massive multiple arrays will be resolved. The optimal array will be larger, perhaps including fixed full-width arrays.

The industrial requirements of the ink make it difficult to formulate lower viscosity ink. Many of the alternative technologies for higher resolution jetting, need a lower viscosity ink (~3cPs) and are therefor of limited use for industrial applications. New chemicals, specifically adapted for jetting inks will become available that will improve the ink performance. However, the ability to jet higher viscosity ink (~80cPs) could be a decisive advantage for a printhead.

Conclusion

Full color digital presses can be built that provide ultra-high speed, variable data, digital color on substrates that vary from thin, flexible film and paper over thin and thick aluminum, laminates, PSA-backed label stock to foam backed vinyl flooring. The productivity is optimized for short run applications, where traditional printing methods can not create profit. Besides the traditional look and feel of ink on substrate, variable data printing enables users to differentiate their products.

The requirements for the printheads and the ink are however different. The first generation of grayscale printheads and UV jetting inks prove that these requirements can be fulfilled, but there is still room for improvement. These price-performance improvements will eventually challenge traditional printing processes even for medium run lengths with the added advantage of more product differentiation.

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Biography

Peter Bracke received his Master degree in Electrical Engineering in 1985. He is the manager of the Strategic Research group of the Industrial Printing division of Barco Graphics, a division he joined in 1999 where he focuses on ink jet technology.

Previously he was a project leader in the Central Research Department of the Barco holding, which he joined in 1985. He worked on many aspects of technology used in the different divisions of Barco such as analog electronics, IC design, RF design, sensors, signal transmission, medical imaging, acoustics, human perception, signal processing and analysis.