Ink development in HP Indigo digital presses

Boaz Tagansky; Hewlett Packard Company; Rehovot, Israel

Abstract

In classical liquid electrophotography the latent image on the photoconductor is developed by electrophoresis of low viscosity low density ink dispersion onto the photoconductor followed by a metering step removing excess liquid. This technology was used in the first generation products that Indigo introduced to the market. As Indigo mastered the color switching architecture and strived for higher speeds, it became evident that simple electrophoresis was limited in its speed capability.

In this paper we describe the novel ink development method employed in more recent Indigo products. A very thin electrically charged, high viscosity and highly concentrated ink paste is applied to an electrically biased elastomeric developer roller, which, when contacting the photoconductor, applies ink to the discharged areas of the photoconductor. The 2nd generation method can support a broad range of printing speeds, from desk top printer level to offset press level, and can accommodate a wide range of ink properties like viscosity and concentration. It also reduces carrier usage and relaxes tolerances around the photoconductor.

With this method, an ink film is electrophoretically applied to the developer roller from low concentration ink dispersion, leveraging Indigo's technology for controlling ink characteristics. The next step compacts and meters the ink layer using a biased squeegee roller. Ink is then selectively transferred to the photoconductor by the electric fields. Finally, the residual ink is electrically transferred from the developer roller surface and subsequently dispersed back to low concentration for reuse.

Introduction

HP Indigo digital presses use liquid electrophotography based on ElectroInk®, with a hot transfer blanket. By using liquid ink, high image quality is achievable at high printing speeds. The hot transfer blanket maintains high quality with substrate independence and minimal impact on the substrate (no fuser).

The architecture of the printing engine of HP Indigo digital presses is shown in figure 1. An organic photoconductor foil (PIP) is placed on a rotating drum. After passing a charging unit (scorotron or charge roller) a latent image is created by a multi-beam laser scanning unit. Then ink is developed onto the latent image by one of the various colored ink development stations (BID units). After ink transfers to the blanket using electric field, the carrier liquid is evaporated off the hot blanket, and the resultant hot melted ink is transferred to the substrate by means of pressure and tackiness. For a sheet fed press this process is repeated once for each color. For web fed press the ink layers accumulate on the blanket and transfer in one contact with the substrate. See [3] and [5] for more general review on HP Indigo technology and presses.

The ink development technology (BID) was developed to answer a need for very high printing speeds, fast color switching, and supporting wide range of ink characteristics. It has been shown to work over a very wide range of speeds, liquid viscosities and ink concentrations. It enables fast color switching within as little as few milliseconds. The BID technology is part of the HP Indigo 7000 press printing at process speed greater than 2 m/s.

Also, as the entire ink development is encapsulated into a relatively small unit that can be serviced from the front of the press, the ease of use of the press is greatly improved.

This paper summarizes the work of many people, starting from the original patents of Landa et al [1] [2] and continuing these days.

***Figure 1**. HP indigo digital press – printing engine schematic*

Principles of operation – ink development

The BID unit works in a three steps cycle (figure 2) involving the developer roller, which is made of an electrically conductive elastomeric layer over a metal core.

The first step is to electrostatically coat an ink layer on the developer roller. The ink layer remains electrically charged so it can be subsequently controlled by electric fields. This layer is a dense, paste like coating rather than liquid. It is thin and uniform as required for good image quality.

The second step is to transfer ink to the PIP onto the latent electrostatic image area. Since the ink layer on the developer roller is very dense, this process step, electrostatic transfer, is much faster than electrophoresis used in classical liquid electrophotography, thus enabling high printing speeds. Also by engaging the developer roller to the photoconductor, ink transfer is stabilized instantaneously, enabling fast color switching.

The third step is removing ink residue from the developer roller. The ink residue is dispersed, electrically discharged, drained into the ink tank and reused.

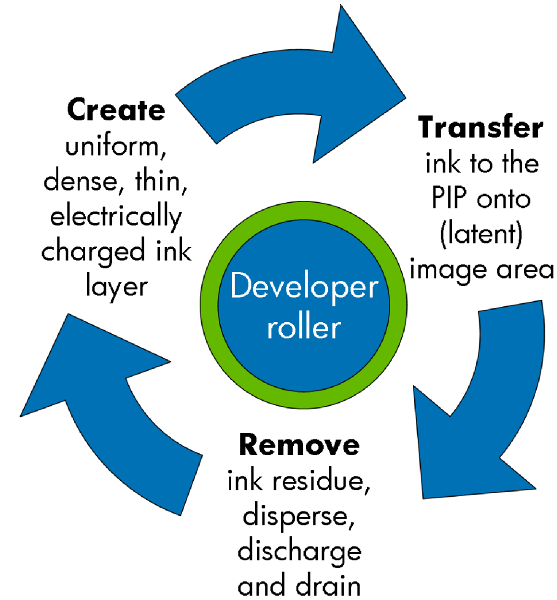

***Figure 2**. BID cycle*

First step – create ink layer on developer roller

To create the ink layer a diluted ink dispersion flows between the rotating developer roller and a stationary electrode (figure 3). The high voltage applied across the gap, with the aid of a charge director, causes ElectroInk® particles to become electrically charged. The particles move in the liquid towards the developer roller, due to the force from the electric field (electrophoresis). The liquid is then metered away by the squeegee roller.

This electrophoresis arrangement is not limiting the printing speed since electrode length can be longer than the nip between two rollers and since the electrode voltage is not limited by photoconductor charging, as in classical liquid electro-photography.

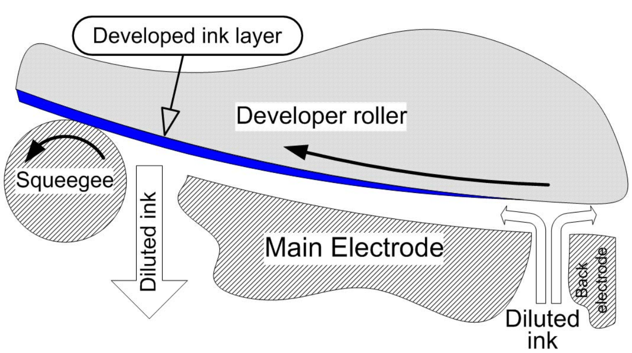

***Figure 3**. First step schematics*

Flow regulation

The flow through the developer-electrode gap is a sum of pressure induced and roller rotation induced contributions. The inlet stream is divided into two, 'forward flow' and 'backward flow' (figure 3). Since the forward electrode is much longer than the back electrode, the forward flow is dominated by the roller rotation, while the back flow is dominated by the pressure. Thus pressure variations mostly affect the back flow which has low effect on ink development.

Developer electrode gap

Within the liquid there are negative ink particles, positively charged micelles, and negative micelles, whose movement is dictated by the electrical and drag forces.

As the negative charges move away from the electrode, a zone containing positive charges only is created. Similarly a negative zone is formed near the developer. These space charges near the electrode and developer roller surfaces reduce the effective field that drives the ink particles. The space charge is more dominant in the electrode area since the ink particles are faster than the micelles, and since the flow near the electrode is much slower.

Squeegee

The electric field under the squeegee is an order of magnitude higher than in the electrode zone. So the ink layer is compressed into higher concentration, reaching paste like viscosity.

Low viscosity carrier liquid is metered away by mechanical forces. We can use an approximated formula for coating with deformable rolls given by [6]:

$$e \propto \frac{\eta^{0.6} \cdot R^{0.7} \cdot V^{0.6}}{W^{0.3} \cdot E^{0.3}} \qquad (1)$$

- e thickness of carrier layer left on top of the dense ink
- W load per unit length between squeegee and developer
- R combined radius of squeegee and developer
- η carrier viscosity
- V process speed
- E dynamic Young modulus of elastomeric layer

From (1) we can conclude that squeegee "pressure" has a very wide operating window ($W^{0.3}$), while reducing the radii has significant influence on minimizing liquid carrier passage ($R^{0.7}$).

Second step – ink transfer to photoconductor

The developer roller is in contact with the photoconductor. In the non-image area the ElectroInk® particles are repelled by electrostatic force. In the image area the ink splits as a function of voltage applied to the developer roller (figure 4).

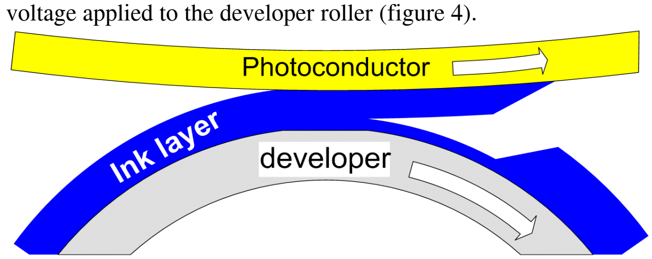

***Figure 4**. Ink transfer to photo-conductor*

Simplified electrical model

Suppose the ink layer is uniformly charged, and the PIP can be considered a dielectric with no trapped charges, and developer is very conductive. Using these simplifying assumptions we can get a diagram of electric field in the development nip (figure 5). To the first order the ink should split between developer roller and photoconductor according to the direction of the electric field. According to the diagram, reducing the developer roller bias decreases the amount of ink transferred to the photoconductor, allowing easy control of color density. An alternative mode of operation can be full ink transfer in the image area. However this would put more emphasis on achieving a very uniform ink layer on the developer roller to maintain color uniformity. Partial ink transfer reduces the tolerance requirements for the system. See [7] for multi-dimensional model.

Care must be used with respect to the simplified model, since it does not take into account many parameters, such as non-electrical forces or non uniformity of ink. As an example more than a minimal field is applied to keep the background area clean from ink residue.

Another factor to consider is that the actual developer roller surface voltage may be lower than the applied bias if the roller is not conductive enough (figure 6). This will result is less ink development than anticipated. Thus some modification of the developer roller material may be required to maintain the surface voltage as printing speed increases.

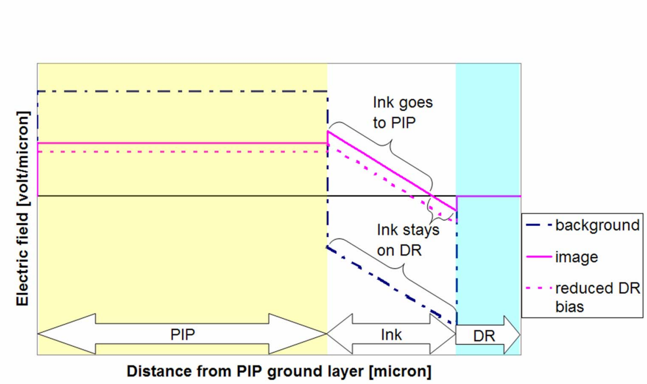

***Figure 5**. Simplified electrical model of ink transfer to photoconductor*

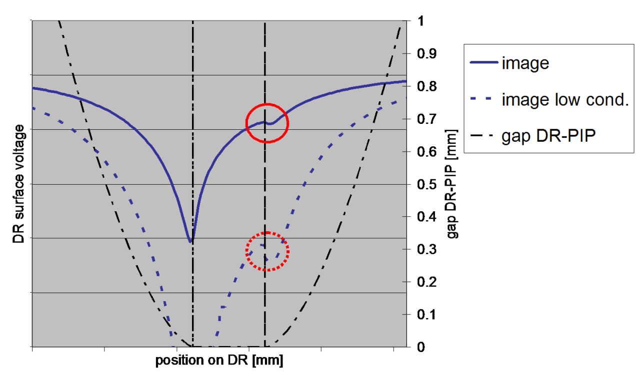

***Figure 6**. Simplified electrical model of developer roller vs. conductivity*

Third step – removing residual ink from developer roller

The residual ink is electrostatically transferred to a metal (cleaner) roller (figure 7). It is then cleared and dispersed into a fresh dispersion flow by a metal wiper, a sponge roller, and a squeeze roller. The diluted ink loses charge to metal surfaces and is routed back to the ink tank. Ink removal is required to avoid ghosting from previous images.

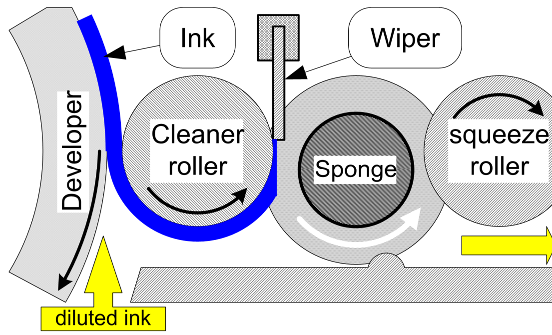

***Figure 7**. Removing residual ink from developer roller*

Control loops of ink development

There are two main categories to consider. The first task is to maintain the right characteristics in the ink that goes into the BID unit. The controlled parameters include temperature, concentration, conductivity, and flow. The second category involves the ink layer formation and subsequent ink transfer to the photoconductor, which are controlled by the electrical biases applied to the BID unit components. See [4] for a general review of control mechanisms in HP Indigo presses.

Challenges introduced from principle of operation

Ink viscosity 'force' tends to split the ink layer approximately equally between the developer roller and the photoconductor, independent of image or background. This can introduce noise into the image forming by the electrical 'force' and increase the probability of leaving some ink on the background area. So ink design is an important part of this technology, to ensure electrical forces dominate the process.

For the color switching architectural design multiple BID units are required to be placed around the photoconductor requiring a large circumference photoconductor drum.

BID design

Figure 8 shows a cross section of BID unit used in HP Indigo 5500 press. The design is relatively compact to facilitate placement of multiple units around the photoconductor. The main electrode also forms the backbone of the unit for structural stability. No wet areas are exposed. The critical parameters are

- Developer roller to electrode gap
- Developer roller speed
- Developer roller voltage
- Developer roller surface
- Ink parameters

The developer roller is clearly the most critical element in the unit. It has to be soft, but without set if pressed; it has to be conductive but not too much; it needs to maintain mechanical tolerances, and have a smooth surface; and it should retain these qualities over a long time.

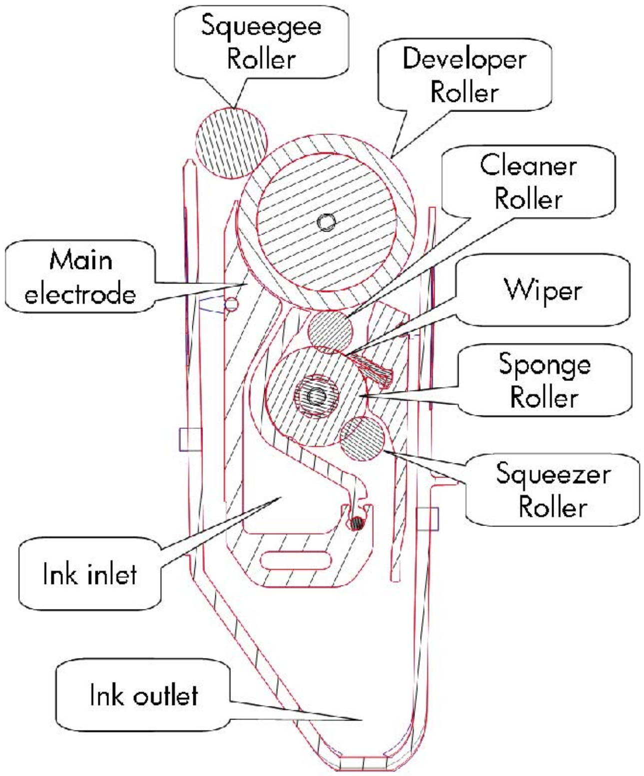

***Figure 8**. Cross section of BID unit used in HP indigo 5500 press*

BID reliability

Main reliability issues are related to ink-BID interactions, developer roller and press diagnostics. Ink-BID materials incompatibility can lead to electro-chemical corrosion and sludge build up on various components. Developer roller itself can degrade due to electro-chemical reactions, become stained by ink or suffer from abnormal press behavior. When rare print quality issues occur that are unfamiliar to the press operator, he may choose to replace a BID unit though it is not faulty.

To achieve reliability improvement actions have been taken with respect to the main issues. This include optimization of BID surface materials to be corrosion resistant and ink repelling, modifications of the ink, optimization of developer roller structure and materials and improved diagnostic tools for the operator. Some diagnostic tools include sophisticated monitors of the electrical currents used in the BID.

The cost related to reliability is the ratio between the cost of the unit and the replacement frequency. When the BID technology was young, this cost was relatively high. Since then cost reductions and reliability improvements reduced the 'reliability cost' by a factor of two every 2 to 3 years.

Conclusion

A novel method of ink development is employed in recent generations of HP Indigo digital printing presses. This method creates a very thin layer of high viscosity concentrated ink on a developer roller, prior to selective image-wise transfer of this ink to the photoconductor. This development technique supports process speeds exceeding 2 m/s, accommodates a wide range of ink viscosity / concentration, reduces usage of carrier fluid, relaxes tolerances around the photoconductor, and improves ease of use.

References

[1] Benzion Landa, Ishaiau Lior, and Ehud Chatow, "Latent image development apparatus", US patent 5596396, (1997).
[2] Ishaiau Lior, Amiran Lavon, and Ehud Chatow, "Latent development apparatus for use in electrophotographic imaging", US patent 5610694, (1997).
[3] Udi Chatow, "The Fundamentals of HP Indigo's Digital Offset Color Printing Process and How It Rivals Mechanical Offset Printing", (proceedings IS&T's NIP18, 2002), pages 125 – 129.
[4] Gilad Tzori, "Control Mechanisms for Print Quality Assurance in HP Indigo Presses", (proceedings IS&T's NIP20, 2004), pages 586 – 593.
[5] Hart Yoram and Tal Riesenfeld, "HP Indigo Industrial Web Presses: Technology and Applications", (proceedings DPP 2005), pages 92 – 94.
[6] Coyle, D. J. , "Experimental studies of flow between deformable rolls." , (AIChE Spring National Meeting, New Orleans LA 1988) Paper No. 3d
[7] Dror Kella and Amiran Lavon, "Optimizing laser print quality phase space modeling", (proceedings IS&T NIP23 2007) pages 73-76.

Author Biography

Boaz Tagansky received his B.Sc. degrees in mechanical engineering and computer science from the Technion - Israel Institute of Technology at 1986 and 1987, and joined Indigo as a mechanical engineer. Later he received his PhD from Tel-Aviv University at 1996. His research interests at Indigo, later acquired by Hewlett-Packard, have focused on the physics of liquid electrophotography. Now he is chief technologist, architecting the printing technology of HP-Indigo printing presses.