Control Mechanisms for Print Quality Assurance in HP Indigo Presses

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Abstract

The challenge of consistently achieving high print quality in HP Indigo digital presses is addressed both by the fundamentals of the liquid, HP ElectroInk™ based electrophotographic printing process, as well as by using a comprehensive set of ingenious control mechanisms. The control loops deal with a wide range of process parameters assuring the accuracy, consistency, and stability of the print quality.

We cover the major print quality related automatic control loops. The paper reviews the liquid ink parameters – concentration, conductivity, flow, and temperature. It also explains how the Organic Photo Receptor (OPC) charge and discharge levels are maintained. At a higher system level, we describe a method of verification of stable and accurate image density, gray level control, and color-to-color registration. A method for obtaining accurate dot positioning and approving high accuracy for duplex printing is presented. The paper reviews the main parameters, measurement devices and related algorithms, and shows how they lead to the consistent high-level print quality characteristic of HP Indigo digital presses.

Introduction

The HP Indigo digital presses are based on the HP ElectroInk™ electrophotographic printing process. This process is based on three technological pillars:

- HP ElectroInk™
- Thermal transfer
- Color switching

This printing process produces the high printing quality required in the commercial printing world with the expected offset look and feel.

The challenge to maintain the highest print quality over time and between different printing engines lies in the control field.

Controlling the print process is a combination of two factors:

- A thorough understanding of HP Indigo printing process fundamentals
- Ingenious development of control mechanisms and control algorithms

Because the process is fully digital, each printed dot can be individually controlled. Control of the dot size, dot location, and dot gain with high accuracy is achievable using the following sensors and detectors:

- An encoder allows real time angular position of the drums; encoder pulses are used to synchronize the tasks throughout the press.
- An inline densitometer (ILD) measures the optical density (OD) of the image in various colors and gray levels.
- An electrometer measures electrostatic charge level on dielectric material. The electrometer is used on the OPC drum.
- A start of scan (SOS) sensor aligns the laser beam to ensure vertical image accuracy.
- A laser power detector measures laser beam power.

The following subjects are covered in this article:

- Fundamentals of the HP Indigo Process
- Laser Imager
- Control Loops in HP Indigo Presses
- HP ElectroInk™ Control Systems
- HP Indigo color and Optical Density Control
- Image Positioning
- Temperature Control

Fundamentals of the HP Indigo Process

The HP Indigo process is based on three technical pillars as shown below.[1]

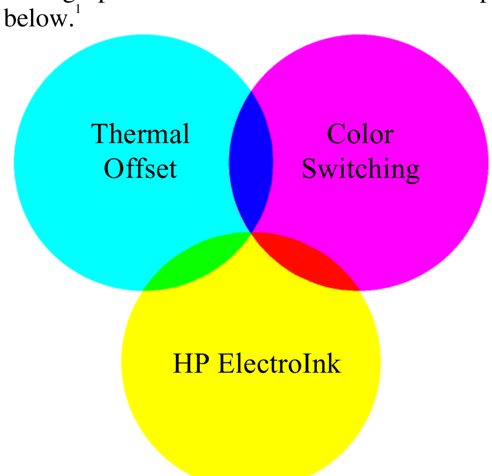

Figure 1. Three technical pillars

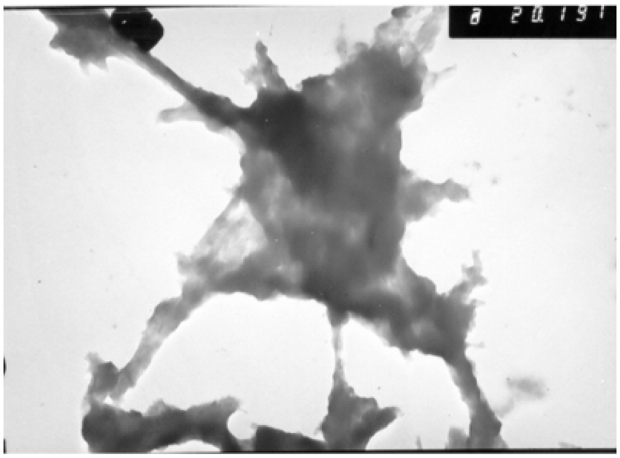

Figure 2. HP ElectroInk™

HP ElectroInk™

HP technology is based on HP ElectroInk™ – HP's proprietary liquid ink. HP ElectroInk™ is a unique tentacular, electrostatically-charged pigmented polymer dispersion in an organic dielectric liquid carrier (Figure 2).

The average mass diameter of an HP Indigo Electroink™ particle is about one micron. These particles are dispersed in a liquid medium, thus achieving numerous benefits:

- The ink layer is similar in nature to a high quality offset ink layer, and "dust affects" are not present.
- The inherent limitation on process speed is eliminated.
- Allows high-resolution images.
- Permits a high quality, uniform gloss that matches the substrate gloss.
- High color coverage per mass ratio, combined with thin image layers, allows a fundamentally low cost per page.

Some of the inherent advantages mentioned above are demonstrated on a chart showing the relationship between process speed and particle size with the relevant print quality attributes. (Figure 3).

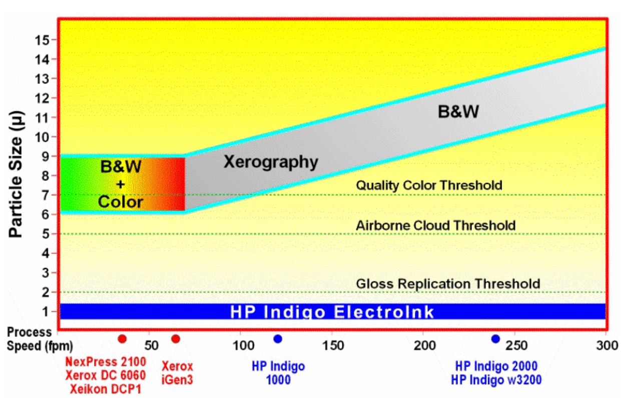

Figure 3. Process speed vs. particle size

Thermal Offset

The HP process uses a blanket heated to approximately 100° C. This causes the specially-shaped, pigmented HP ElectroInk™ particles to melt and blend into a smooth tough polymeric film. When it contacts the cooler substrate, the HP ElectroInk™ immediately solidifies, strongly adhering and transferring to the substrate. The print is effectively dry as soon as it leaves the blanket, eliminating any risk of ink 'set-off' marking other copies. This is a major benefit over conventional lithography that requires either assisted drying systems, or a 'natural' drying time of several hours, before any print finishing processes can be applied.

Color Switching

The HP Indigo Digital Offset Color printing technology with its inherent high process speed allows the printing of all color separations in a single printing engine with one laser scanner and one photoconductor drum.

The HP Indigo Process

Every HP Indigo series II engine has a 12-beam laser imaging head exposing the Photo Imaging Plate (PIP) with a resolution of 812 x 2400 dpi.

One of the seven predefined colors is selectively applied to the latent image previously impressed on the PIP.

The development process is called Binary Ink Development (BID).

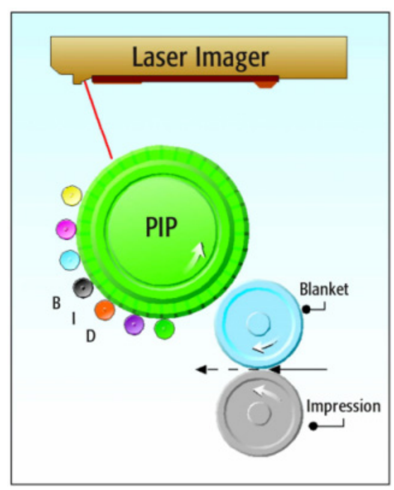

Figure 4. Binary ink development (BID)

The HP ElectroInk™ layer is created as a uniform ink film on an elastomeric roller within a BID unit. The ink is electrically transferred from the BID to the imaging surface on the PIP as an image. Negatively charged ink transfers to discharged areas on the PIP, while the negatively charged background areas on the PIP remain free of ink.

The development or process speed in these presses is 73m/min (240 ft/min). This high speed process using small particles is enabled by the use of liquid ink.

The image is electrostatically transferred from the PIP to the blanket. On this heated blanket, the particles partially melt and blend together until the image becomes cohesive and tacky.

The image is then ready to be transferred completely to the paper—without splitting the ink film. When the ink comes into contact with the substrate, which is significantly below the melting temperature of the ink, the ink solidifies, sticks to it, and 'peels' off completely from the blanket, ensuring 100% transfer from the blanket to the substrate. The blanket is therefore clean and ready to accept the next impression as it rotates past the PIP cylinder.

HP has two alternate transfer sequences: the Multi-Shot process and the One-Shot process. In the Multi-Shot process, all color separations are accumulated on the final substrate. The substrate is held on the impression cylinder for several rotations as it receives all separations in sequence. In the One-Shot process, accumulation of the separations occurs on the blanket, and the full color image is transferred in one shot to the substrate.

Laser Imager

The exposure system of the digital printing engine transforms the digital image data stream into a charge image on the PIP. The system developed by HP Indigo is consists of laser light source, collimator, polygon scanner, and Anamorphic F-Θ scanning optics. The unique combination of very high process speed (1.2 m/sec) and high resolution (800 dpi) for A3 size prints results in printing at the extremely high data rate of 440 Mpixel/sec.

To achieve high quality for such challenging requirements, the optical design was uniquely designed for the use of a 12-beam laser diode array in conjunction with a 6-facet high-speed (33,000 rpm) polygon scanner. To maintain imaging spot uniformity with sufficient focal depth, it was necessary to achieve high dynamic optical performance (especially flatness) of the polygon system. This objective was achieved by stringently controlling optical surface shape quality, and by accurately adjusting the scanning optics.

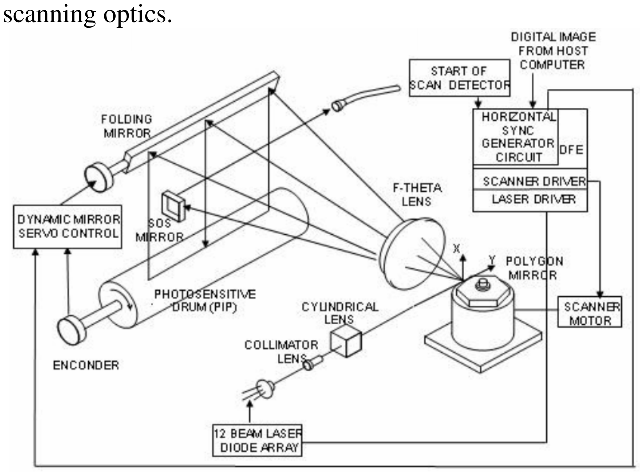

Figure 5. Laser Imager / Writing head diagram

Control Loops in HP Indigo Presses

Figure 6 shows a simplified representation of HP Indigo presses. It shows the entire printing process is based on three major inputs—the digital image, the ink, and the substrate.

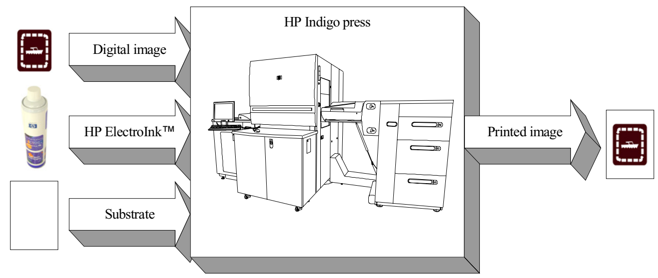

Figure 6. Press block diagram

Figure 7 shows the dominant HP Indigo press control systems affecting print quality. The output is a printed image representing the digital file. Notice that the control loops are interdependent.

The main control loops are divided into four control categories:

- HP ElectroInk™ properties
- Color and optical density
- Dot and image location
- Temperature and environmental

HP ElectroInk™ Control Systems

The ink control system maintains the constancy of parameters that directly influence the accuracy of the printing process.

These parameters are:

- Ink concentration
- Electrical charge of the ink particles
- Ink flow rate to the BID unit
- Temperature of the ink dispersion

Ink Concentration

The ink concentration in an uncontrolled system would monotonically decrease, since in the printing process the ink particles leave the printing mechanism while its carrier liquid returns to the ink tank. To compensate, ink particles are replenished from the ink concentration cans. A concentration sensor continually monitors ink concentration.

The output signal of the concentration sensor is the input signal for the ink replacement algorithm that, according to the need, activates a pneumatic system that pushes out concentrates from the ink cans.

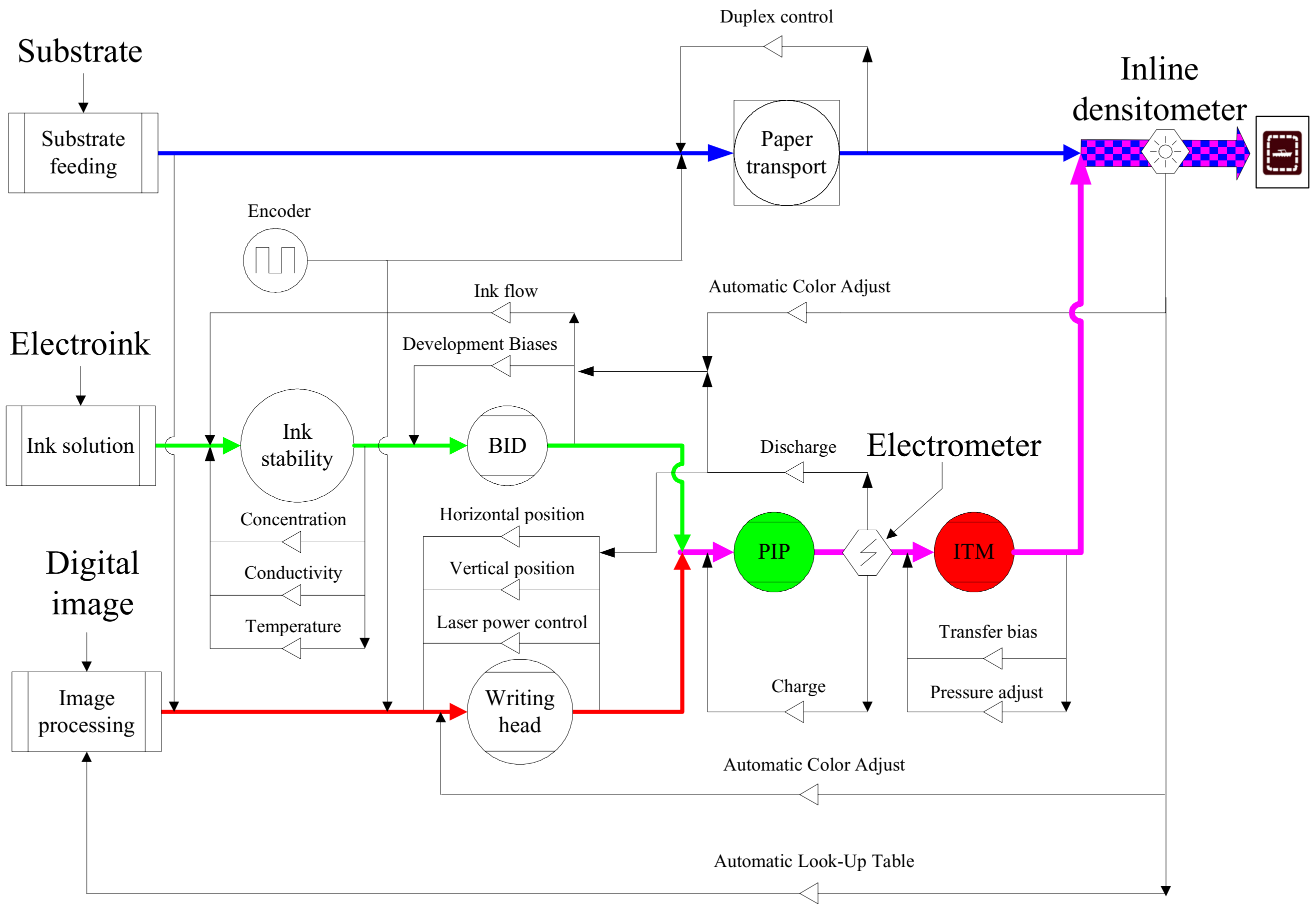

Figure 7. HP Indigo press control scheme

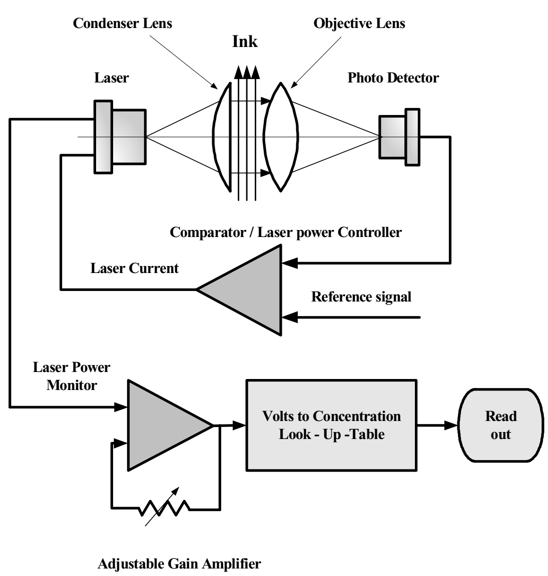

Figure 8. Ink concentration sensor

The concentration sensor is an optical sensor that measures the light attenuation caused by the ink. Higher particle concentration in the transparent carrier liquid causes larger light attenuation. The sensor contains a diode laser as a light source, lenses, and a photodiode detector.

Ink flows between the condenser and objective lenses. The sensor circuitry contains an inner closed loop control system—the optical power of the laser diode is controlled to keep the level of light intensity constant on the detector. The output signal of the sensor is taken from the photodiode monitor built into the diode laser. Thus, laser power, and consequently the photodiode monitor output signal, increases with increasing concentration. Although light attenuation varies by three or four orders of magnitude from yellow ink to black ink, the wide range of optical power from the laser diode accommodates it. This sensor adapts to all color variations.

The geometry of the applied optics allows measuring light attenuation caused by both absorption and scattering. In black ink, absorption causes most light attenuation. In yellow, magenta, orange and white inks, for a given wavelength of the laser, scattering is the dominant factor leading to light attenuation. The sensor is also capable of measuring transparent ink concentration due to the difference of the refraction indices of the particles and their carrier liquid.

Ink Conductivity

The electrical charge of the ink particles is controlled by adding charging agent to the ink dispersion. The molecules of the charging agent attach to both the particles and their carrier liquid. The need for a control system arises from the fact that the ink particles leave the printing mechanism, while the liquid carrier returns to the ink tank. As a result, the balance between the charging agent bound to the particles and the part that is dissolved in the carrier liquid can change during the printing process. Although ink particles bring some charging agent with them from the concentration cans, this is an inherently unstable process. Note that the charging agent cannot be removed from the dispersion by any other means than printing. Thus for stable control, the system must be designed for a monotonic decrease of the charging agent concentration, and the charging agent needs to be added on demand. To maintain the charging agent concentration at a constant level requires maintaining the electrical charge of the ink particles at a constant level. The concentration of the charging agent can be monitored due to the presence of charging agent in the dispersion. The charging agent causes an extremely small, but measurable electrical conductivity in the ink dispersion. Thus, the electrical conductivity of the ink is continuously measured and fed into the controlling algorithm. Electrical conductivity is kept constant by adding the necessary amount of fluidized charging agent. The conductivity is measured by monitoring the current flow between two electrodes immersed into the ink.

Conductivity =
(Current/Electrodes area) / (Voltage/Electrodes Distance)

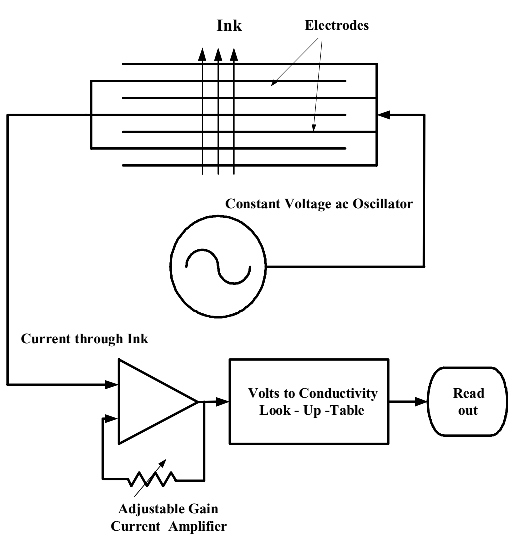

Figure 9. Ink conductivity sensor

In order to avoid ink particles depositing on the electrodes, a low amplitude alternating voltage is applied between the electrodes. The component of the current in phase with the applied voltage is measured.

Ink Flow Rate

Ink flow rate is determined by measuring the time it takes for the ink to flow from the activated ink tank to the corresponding BID.

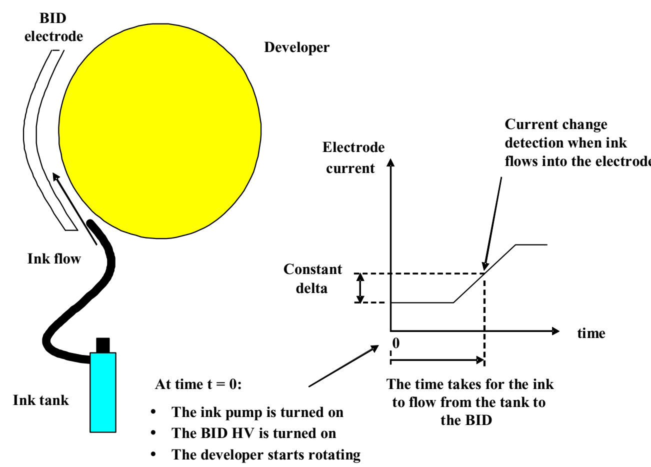

Figure 10. Ink flow rate

This control loop takes advantage of HP ElectroInk™ and BID unit properties. As long as the gap between the electrode and the developer is filled with air, no electrical current exists between them. As soon as ink fills the gap, the electrode current ramps up, indicating that ink reached the BID unit. The ink flow rate is calculated using the elapsed time for the ink to flow from the activated ink tank to the corresponding BID, and the ink volume.

HP Indigo Color and Optical Density Control

Color control plays a major role in production printing and proofing. An efficient color control system achieves color accuracy and consistency, within a single printing engine, and across printing engines.

To control color, printed ink thickness and dot size must be controlled. This is performed in progressive steps during the printing process; figure 11 represents an overall view of the color and optical density (OD) control system.

All color calibration in HP Indigo presses is performed and measured automatically using an inline densitometer, and requiring no operator intervention.

PIP Charge Control

The printing process is based upon electrical fields being applied to the ink in various printing process phases. Two parameters that must be set for the PIP are its ambient charge level prior to laser discharge and its charge level after laser discharge.

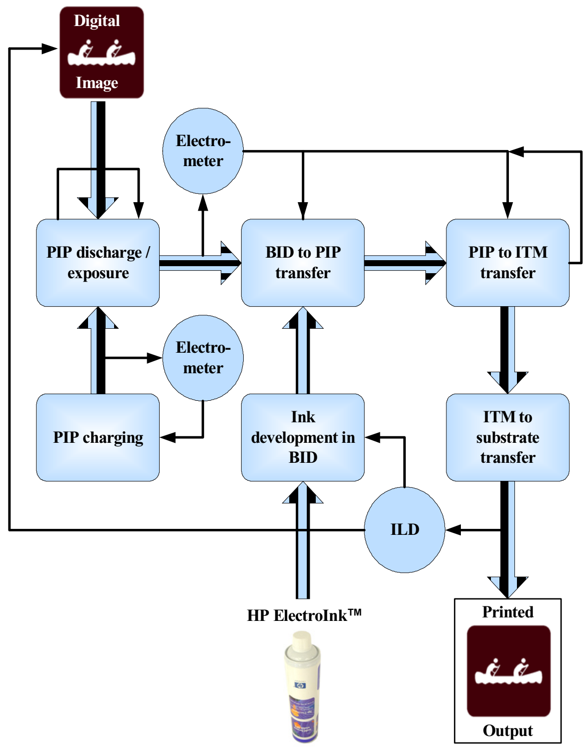

Figure 11. Color and OD control

An automatic procedure calibrates the amount of charge generated by scorotron charging units. Calibration is performed by adjusting the scorotron wire voltage to produce a specific charge current.

Three goals are in view:

- Check uniformity of the spatial PIP charge to ensure color spatial consistency
- Measure PIP surface voltage after the PIP has been charged
- Calibrate the charge applied to the PIP prior to the discharge phase

Perform all these calibrations automatically using an inline electrometer; an electrostatic voltmeter measures the PIP charge level.

Calibration of the Dot Gain Look-Up Table

Dot gain is a common phenomenon in all printing presses. Mapping the dot gain of the press is crucial for achieving color accuracy and consistency. The control loops use dot gain LUTs (Look-Up Tables) to compensate for the inherent dot gain of the press. The calibration procedure adjusts the halftones, decreasing or increasing coverage within the halftone superpixel using the dot gain LUT.

Dot gain is influenced by some process parameters and varies with time. Therefore, in order to calibrate the press colors, the dot gain LUT is measured and calibrated from time to time. This procedure does not change the actual pixel size, but digitally compensates so that the press prints the same Dot Area coverage using different pixel sizes. Pixel size changes cause prints to appear different, even though the colors are identical. Binary data, such as text and barcodes, is not affected by this calibration; binary data changes with variations in the actual dot gain of the press.

Physical Parameter Adjustment

In the HP Indigo Electro-photographic process, there are two controllable parameters that influence both the size and thickness of superpixel dots to obtain the desired colors:

- Developer voltage – ink is deposited on the PIP discharged area in proportion to the difference in electrical charge between the developer and the PIP. Increasing the voltage between the developer and the PIP causes more ink to be deposited.
- Laser power – increasing laser power increases the cross sectional area of the light beam. This effect has a strong influence on printed images. A larger laser cross sectional area means a larger discharge area, and hence a larger diameter pixel.

The combined effect of laser power and developer voltage plays a key role in color control. By adjusting these parameters, we can obtain precise control over two key points of color performance:

- Solid Optical Density – the thickness of the ink layer in these areas determines the perceived color, as well as the visual quality of the outline sharpness in the image.
- Dot Area (DA) coverage – the output is adjusted to result in the specified coverage percentage.

By adjusting the laser power and the developer voltage in an iterative, closed loop control algorithm, these two color parameters are very accurately controlled. A change in the 75% gray level causes a corresponding, smoothly varying change in all gray levels.

Physical parameter adjustment is performed using the last calibrated dot gain LUT, which corresponds to the actual, physical dot gain of the press. Therefore, we achieve color control over the entire range of color output by adjusting the solid and the 75% gray levels.

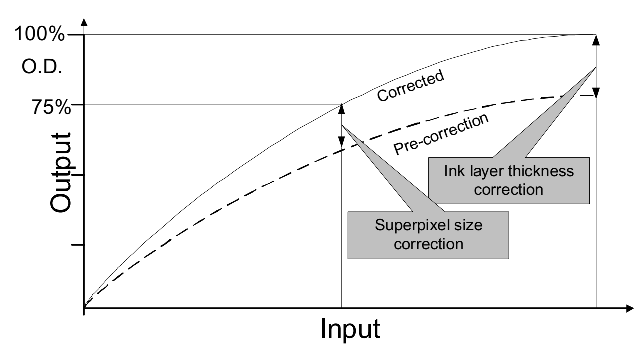

Figure 12. Optical density correction

Image Positioning

Dot Positioning and Image Quality

Dot and image positioning are major contributors to overall image quality. Image quality is defined by:

- Accurate dot positioning
- Accurate line spacing
- Color plane registration
- Front- to-back image alignment

Figure 13 depicts the control loops affecting image location and positioning.

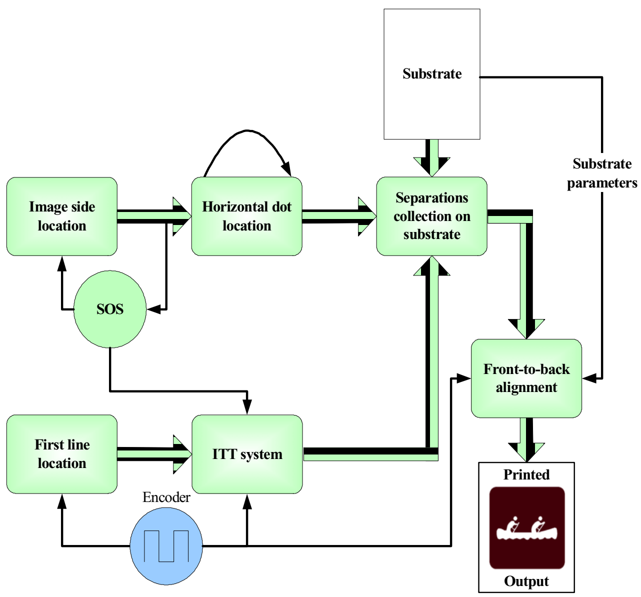

Figure 13. Dot positioning

The HP Indigo ITT[2] system plays a major role in accurate positioning. The ITT system controls dot positioning, line spacing, and color plane registration.

The control is performed using three sensors:

- The encoder is attached to the PIP drum axis—it transmits accurate PIP angular position data.
- Dynamic mirror, angular position sensor.
- SOS (Start of Scan) sensor that detects the beginning of each line, so that the SOS sensor also acts as the scanner motor encoder (figure 5).

A closed-loop controller obtains data from all sensors. It calculates the position error between the scanned beam and the PIP drum positions. The correction signal is fed to a torque motor that uses it for error compensation.

The ITT system is used to achieve both correct line spacing and color plane registration.

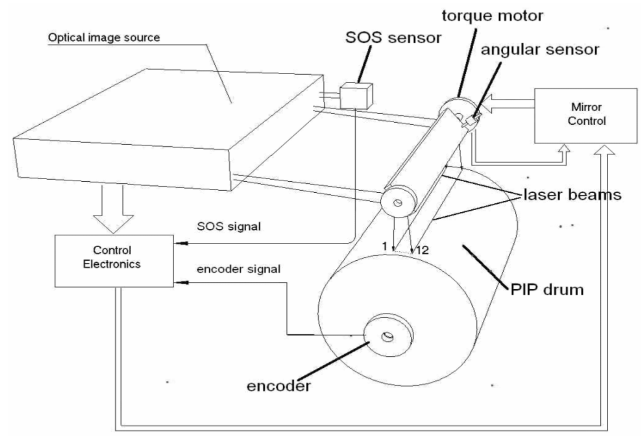

Figure 14. ITT image tracking system

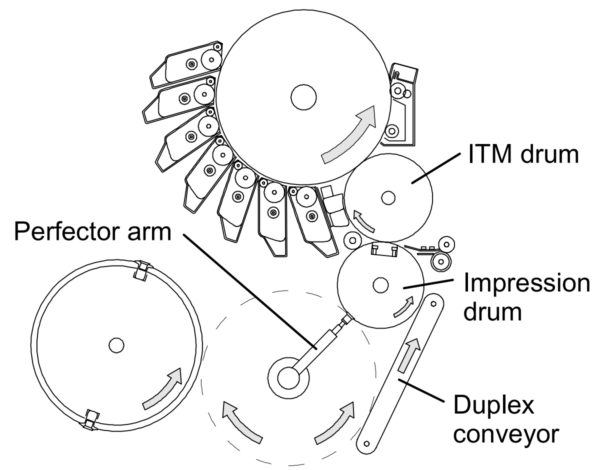

Figure 15. Duplexing system

Duplexing

Duplexing capability is essential to digital offset presses; this capability allows printing of VDP (Variable data printing) jobs, and allows collation of jobs with ease. After printing the first side of the substrate on the impression drum, the perfector arm grasps the leading edge of the substrate and peels it from the impression drum. Using vacuum forces, the perfector arm holds the substrate, and rotates clockwise until the substrate lays on the duplex conveyor. This action is performed while the press is rotating.

Next, the perfector arm rotates counterclockwise and the substrate is fed back to the impression drum. The substrate moves along the duplex conveyor; the exact location of the substrate is controlled by the perfector arm servo motor control system.

The motion profile of the perfector arm is determined by substrate properties and the angular position of the impression drum. The impression drum location is monitored in real-time via the encoder; this allows high accuracy front-to-back image alignment, regardless of substrate dimensions.

Temperature Control

Temperature control of the major elements is performed using straightforward control algorithms. Temperature control is provided for the press internal space as well as for the three main components—the PIP, ITM, and impression drums.

References

1. Udi Chatow, Ronen Samuel, Digital label printing, IS&T NIP, pg. 476 to 481.
2. Haim Livne, Michael Plotkin, High-speed laser scanning, IS&T NIP19, pg. 472 to 475.

Biography

Gilad Tzori received his B.Sc. degree in Mechanical engineering from the Technion – Israel Institute of Technology. Since 1988 he has worked at HP Indigo, Israel in several R&D positions, among them System Engineer, Program Manager, and since 2003, as R&D Existing Products Section Manager.