Challenges of Replacing Automated Screen Printing of Plastic Parts with UV Curable Single-Pass Inkjet

Paul Beliveau and Henry Mossell
FUJIFILM Dimatix, Inc.
Lebanon, NH, United States of America

Abstract

Fujifilm Dimatix's Inkjet Technology Integration team worked closely with a team of end-user manufacturing engineers to develop and deploy 5-color (white, black, cyan, magenta, and yellow) UV curable inkjet printing on a 10" by 12" ABS part. The challenges and solutions of ink selection, part pre-treatment, creating an over-printable white base layer, pinning, managing ink spread, and final cure are detailed.

Application

A medical device manufacturer, with an existing automated screen printing line, wished to replace the screen printing line with a high throughput UV curable inkjet print system. The surface to be decorated was a sheet of injection molded clear ABS approximately 10 inches by 12 inches. The medical device company needed to be able to produce about one million parts per year across a family of about 20 variants, each with unique images. The existing process printed the clear ABS with three colors. All devices were printed with white and black, creating windows with graduations. In addition, a unique spot color, which denoted designs within the family, was added to each device. As an inkjet application, the spot colors would be recreated in process color. In the device's history, users had discovered that the screen printed white ink could be written on with a ballpoint pen, which had become a requirement for any replacement inkjet technology.

Sampling

With the participation of manufacturing engineers from the medical device manufacturer, two-color print samples were produced to establish basic feasibility of producing product with similar quality as the existing screen printing equipment. The samples were produced at 400 dpi x 400 dpi with two SG1024MA printheads printing white and cyan commercial UV ink (Formulation 1). By printing a 2.5 inch by 12 inch portion of the final application image onto the ABS panels, the team was able to confirm that the general appearance of the printed image was in line with the existing screen print process, the graduations were clear and accurate, and the white ink was able to be marked with a ballpoint pen. Although this test answered the most basic questions, it was done with very slow speed equipment that was unable to be used to size the design correctly for full scale up.

Figure 1 - Example of Image Quality Achieved in Early Samples (Photo from Full Scale System Print) that Highlights the Graduation Marks and General Print Quality

A three-color, five inch wide 400 dpi system was built with a Honle UVAHAND250 between color one and colors two and three as a pinning lamp (although the final system would utilize five colors (white, black, cyan, magenta, and yellow) only three were tested as this was the maximum ink thickness expected in creating the target colors from the process colors). A five inch, 300 watts per inch cure lamp was used to final cure the printed samples. A 3DT Multidyne corona treater was used to pre-treat the ABS panels under test. The printing was completed on a linear slide with a top speed of 40 ips (inches per second), 80% of the final target print speed. A block diagram of the print process being modeled in the test is shown in Figure 2.

The system was used to determine the equipment sizing. By varying the time to cure of a single white layer of ink, the time required for the ink to spread into a single continuous film was determined. By varying the speed of the test panels under the pinning lamp, the required pinning energy was determined. The values from the small scale testing are noted below. The values determined in the small scale test were scaled to the target print speed of 50 ips.

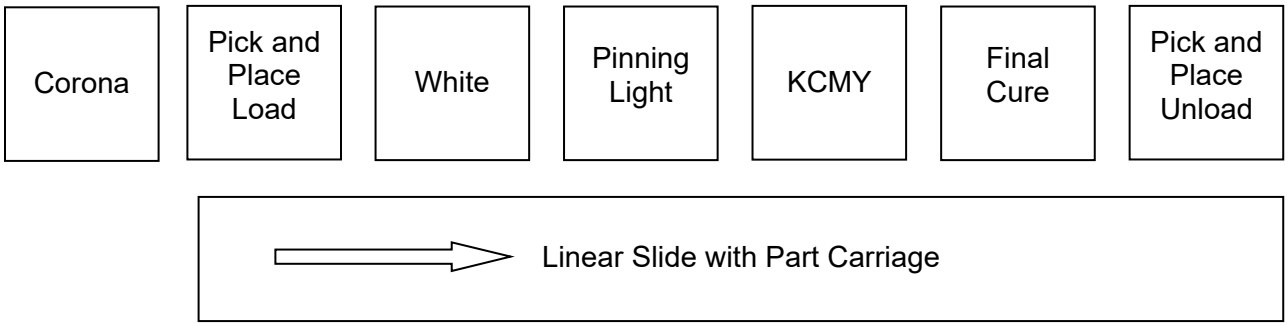


Figure 2 - Block Diagram of Print System

Developed Process

1. Corona treat the panels to >40 dynes/cm
2. Scan the panels through the print, pin, and cure zones at 50 ips (250 fpm)
3. Print white under all printed colors and any required white areas.
4. Allow the white ink to spread for 0.25 seconds before entering the pinning zone.
5. Pin with 62.5 watts per inch
6. Print the remaining four colors, KCMY
7. Cure with 600 watts per inch

Full System Design

Based on the results from the small scale testing, a full system was constructed. The system consisted of five printbars, each with four SG1024MA printheads arranged to print ten inches wide and two Honle medium pressure mercury arc lamps. The print array was positioned over a precision linear slide provided by the manufacturing team of the medical device company. The slide had a location for the device to be loaded onto a part nest, followed by a short acceleration zone. The print system was supplied treated parts from a 3DT Multidyne system arrayed to a width of 10 inches and integrated with a conveyor. Figure 3 shows an annotated view of the full scale print array, which matches the list below.

1. White Printbar
2. Zone for the white ink to spread into a film (14 inches)
3. Pinning lamp (300 watts/inch adjustable from 15% to 100%)
4. Black, Cyan, Magenta, and Yellow Printbars

5. Final cure lamp (600 watts/inch, adjustable from 15% to 100% output)
6. Alignment backplate
7. Printbar slides to provide access for maintenance

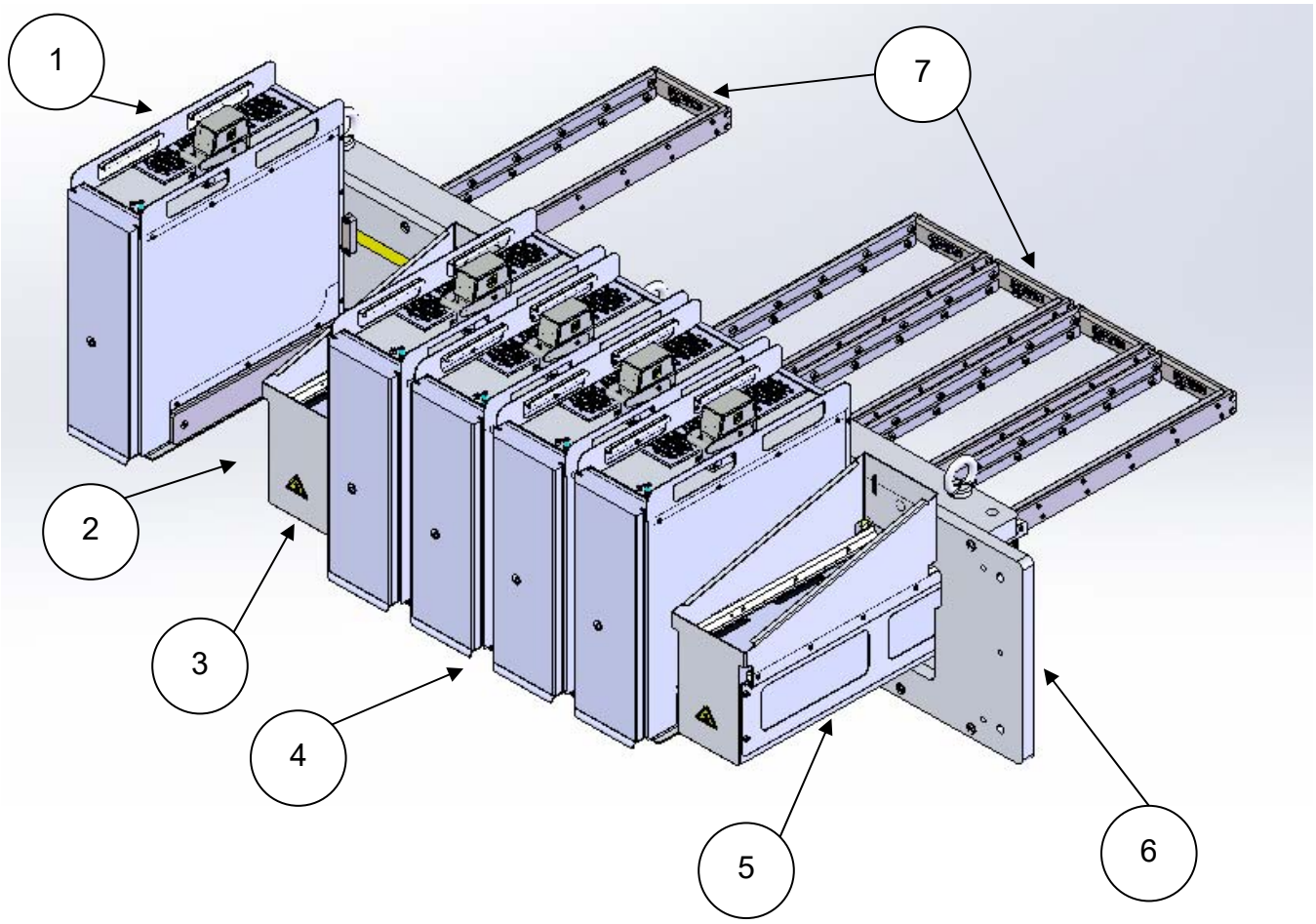


Figure 3 – Annotated View of the Full Print Array

Full System Testing

The system was iteratively tested and adjusted to achieve image quality, adhesion, and write-ability consistent with the existing automated screen print equipment. In all tests, the printed white layers were able to be suitably marked with a ballpoint pen; however, optimizing the adhesion and image quality often were conflicting efforts.

Optimizing Adhesion

During the full system testing, the manufacturing engineering team for the medical device company requested an increase in the adhesion as measured by ASTM D-3359,

Standard Test Methods for Measuring Adhesion by Tape Test. The desired result was a five on a five scale, with previous results averaging three on the five scale. The tape test consistently showed the weakest bond to be the white bond to the underlying ABS substrate, with no separation of the colors from each other or the white underprinted layer.

As the adhesion achieved in the full system was consistent with the adhesion achieved in the small scale test, the most likely route to improved adhesion was to explore inks with more aggressive adhesion; however, variations in the pre-treatment of the medical device were tested before new formulations were explored, as changing the pre-treatment would be more straightforward. Neither additional corona treatment, nor plasma treatment yielded any improvements. With pre-treatment providing no benefit, several white formulations were tested for adhesion with the tape test after multiple passes under the final cure lamp. This ink screening led to the adoption of Formulation 2 being chosen as the white base to underprint the top layers of color, which remained Formulation 1.

With the change in formulation, two cure factors affecting adhesion were analyzed. The two factors explored were variation in pinning lamp height from the substrate and pinning lamp intensity (final cure power in these tests were set at three passes at 25 ips under a 600 watts per inch Honle medium pressure mercury arc lamp). The tape test results from the variations of the two explored factors are included in Table 1. Examples of tape test results are shown in Figure 4. From the table and the photos, the importance of having the pinning lamp focused can be seen.

Table 1 - Effect of Pinning Lamp Focus and Intensity on Adhesion of Fully Cured Devices

Focus Offset	Pin Lamp Power	Adhesion
-1 mm	15%	2,3
-1 mm	18%	2,1
-1 mm	20%	1,5
-1 mm	23%	0
0 mm	15%	5
0 mm	20%	5
0 mm	23%	5
1 mm	15%	3
1 mm	18%	2
1 mm	19%	1
1 mm	23%	0
2 mm	15%	3,2
2 mm	18%	2,1
2 mm	20%	2,1
2 mm	23%	1,0

Tape Test Results - 1 mm

Tape Test Results - 0 mm

Figure 4 - Example Tape Test Results

Optimizing Image Quality

The change in the white ink formulation had major effects on optimizing the image quality. The most challenging effect was a much diminished ability to form a continuous film of white capable of being over printed with process color.

The first challenge encountered was Formulation 2 did not spread as well as Formulation 1 had in prior testing. Two tests were run to gain insight into improving the spreading of Formulation 2, the contact angles of both inks were measured on samples of the ABS substrate and pretreatment effects on spreading were investigated using the following procedure.

For the substrate, multiple 1” square pieces were cut from the cover of a single medical device. These pieces were treated with corona, O_2 vacuum plasma, corona and isopropyl alcohol (semiconductor grade), or not treated at all. Prior to treatment, each sample was also lightly wiped with a clean room wipe to remove any surface contaminates prior to depositing inks on them.

Both Formulation 1 and Formulation 2 white UV inks were deposited on the substrate. Three drops from each ink were placed on the same treated substrate and measured with VCA Optima. The results are recorded in Table 2.

Table 2 - Results of Contact Angle Measurements

Ink	Treatment	Contact Angle			Mean	Std Dev
Formulation 2	None	16.8	17.1	19.2	17.7	1.3
Formulation 2	IPA	13.2	14.2	11.1	12.8	1.6
Formulation 2	Corona	12.1	12.3	10.2	11.5	1.2
Formulation 2	O2 Plasma	14.7	12.2	11.6	12.8	1.6
Formulation 2	Corona + IPA	12.4	12	13.8	12.7	0.9
Formulation 1	None	37.8	35.2	37.3	36.8	1.4
Formulation 1	IPA	11.3	13	12.2	12.2	0.9
Formulation 1	Corona	16.3	14.9	16.9	16.0	1.0
Formulation 1	O2 Plasma	12.5	12.3	12.7	12.5	0.2
Formulation 1	Corona + IPA	22	17.9	19.8	19.9	2.0

Although Formulation 2 achieved lower equilibrium contact angles for all comparison test conditions, which would normally suggest better spread, Formulation 2 did not produce continuous films for any of the treatment methods when printed at 50 ips. The inability of Formulation 2 to form a continuous film at the same speed as that of Formulation 1 suggested that the speed at which the two inks achieve equilibrium may be the key metric separating the performance of the two. The spread dynamics were not measured to confirm this hypothesis, as this level of understanding did not appear to further the goals for this project, since the spread dynamics was not a characteristic of the formulation that could be easily adjusted.

With the results of the effect of pretreatment on spreading collected and providing no path to forming a continuous film at 50 ips, an investigation into the amount of time required to sufficiently spread the ink was conducted. By printing a series of devices with a series of velocity profiles, it was determined a 100% increase in time to spread was required to produce a continuous ink film. The manufacturing engineering team of the medical device manufacturer evaluated the slower processing speed and was able to determine that the change in speed did not affect the overall efficiency of the larger automation system.

The reduction in print speed and the formulation change required revisiting the pinning energy required to provide a white underprint layer, on which the process colors would spread properly and not de-wet. To evaluate the correct pinning level, the cure intensity was varied and the dot gain of the white ink was measured as a means of evaluating the level of cure achieved in the pinning process. As can be seen in Figure 5, the transition between fully fixed and partially mobile occurs between 18% lamp power and 15% lamp power. These numbers are paralleled by observation of de-wetting of ink at 18% lamp power and spread of the ink at 15% lamp power, as shown in Figure 6. It should be noted that the decrease in process speed removed the adjustability of the pinning lamp, with the lamp being turned as low as possible to prevent over pinning the ink.

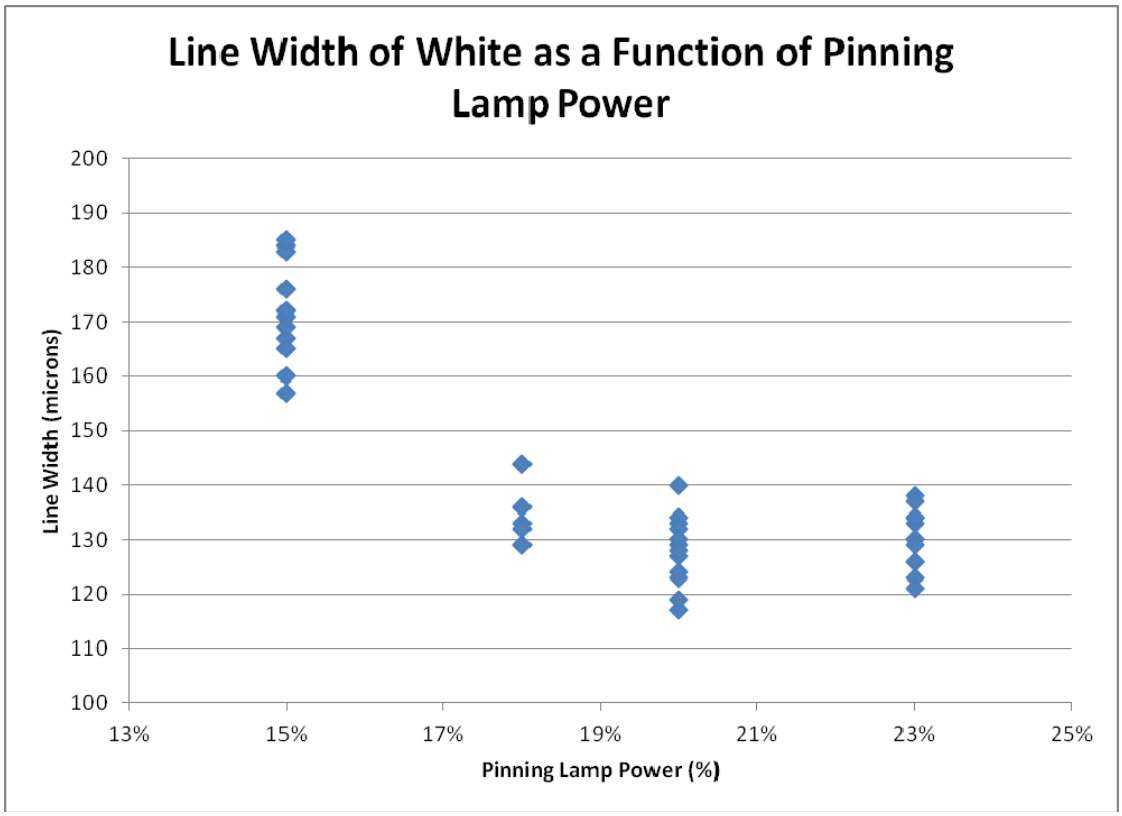
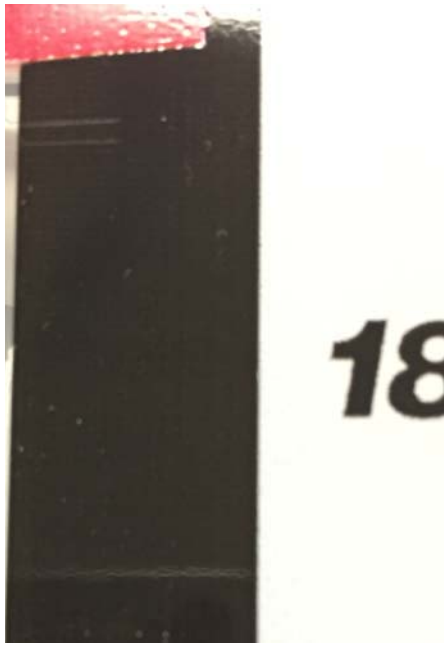


Figure 5 - Chart of Line Width as a Function of Pinning Intensity

Wetting at 18% Lamp Power



Wetting at 15% Lamp Power

Figure 6 - Example Wetting at Two Lamp Power Settings

Summary

In concert with the manufacturing engineering team of a medical device manufacturer, the creation of a single-pass UV curable inkjet print system was produced and tuned to print graphics consistent with the existing automated screen printing system being used for decorating the medical devices today. The effort progressed from basic sampling, through small scale testing, and to the testing required to tune the system. A request to increase the adhesion during the full system test required all aspects of the print process to be re-evaluated, starting with specifying an ink with better adhesion properties. In addition, the spread of the new under-printed white ink required the system to run at half the speed used in sizing all of the equipment, which necessitated careful evaluation of the pinning power required.