Performance of an On-Line Closed-Loop Color Control System

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Keywords: Color, Process, Control, Automation, On-Line

Abstract: With the advent of on-line closed-loop color control devices, there are high expectations on the performance of such systems. Printers expect and manufacturers claim an elimination of "drift", or long-term variation and a reduction in short-term variation, or "noise" in the process of maintaining solid ink density on a web offset press. Additionally, these systems claim to automatically drive the press during makeready to programmed target densities.

This paper will show the results of such a system and its performance on these issues in a real-life printing environment and contrast the system to an open-loop approach, both in a hands-off mode and with operator intervention. Results will be quantified and conclusions will be drawn.

Background

Automation in the printing and related processes has long been sought after for benefits in efficiencies, consistency and quality, and to a large degree has been accomplished to some level. In lithography, as well as the other printing processes, much of the automation has been in material handling such as web splicing, auto feeders, and post-press activities including stackers and conveyor systems. Other than automated register controls, there have not been any significant advances in automation that contribute to the consistency of the output of the printing process until recently, namely closed-loop color control systems.

The use of color measurement to control the color output of the printing process has long been accepted and used, mainly densitometry but more recently

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spectrophotometry. Regardless of the measuring system, an automated collection and interpretation of an appropriate number of readings as well as automated corrections, until recently, has not existed. Though off-line devices (both x and x-y) have existed for some time, the fact that they are off-line detract from their ability to support a more real-time correction of ink keys in a lithographic press. In addition, in most cases the devices strictly report the densitometric or spectrophotometric data and require human subjective interpretation of the data. Granted, some vendors have been able to drive the ink keys to achieve either gray-balance or solid ink density (SID) aimpoints, but they still suffer from the fact that they are off-line. The vast majority of color measurement in the pressroom is done by hand. Data measured this way are even more time-intensive and less timely.

Also at times, in order to read color bars, waste must be incurred in order to read the color bar. Some web layouts place the color bar at the fold and in order to read it off-line, the print-to-fold register must be moved so that the color bar is not damaged and is readable. This creates waste.

Another problem has been the difficulty of measuring the entire width of the press sheet or web. Ideally, data from each ink key zone for each color should be gathered to accurately monitor and control the process. To measure the SID of each ink key position for each printing unit can be a daunting task. For example, on a Heidelberg M-3000 8-unit web offset press, there are 34 ink keys per printing unit. For the entire press and assuming full web width, that means there are 544 total ink keys (8 units X 2 sides (top & bottom) X 34 ink keys) and possible adjustments, not counting sweep adjustments for the ink fountain and dampener. If hand-held measurements were taken at a rate of one reading per second (if that were possible), it would take well over nine (9) minutes to read all of the patches. At a conservative 2,000 feet per minute, more than 18,000 feet of paper would be consumed in just the measuring process. Additional time would still be required for the interpretation of the readings and the resulting adjustments. Much out of conformance product could be generated and result in higher waste.

Additionally, not only is the interpretation of the data subjective, but so is the potential resulting corrections to the ink keys. As is well known, different operators will interpret data differently, will make different adjustments, and will not be entirely consistent day in and day out. Furthermore, operators cannot accurately determine the rates at which density will change, per color and the amount of take-off, as a result of ink key adjustments.

On-press systems, on the other hand, automate each of these manual operations. The color measurements are done on the (web) press, typically in the chill section, via a scanning measurement head. No waste is incurred in reading the color patches. The measurements are performed very quickly and each ink key zone is measured. Interpretation of the data is done via computer algorithms and is ***objective***. The resulting ink key adjustments are done automatically and concurrently. Additionally, rates of change in density are monitored and taken into account for future ink key adjustments so as to not over or under correct the ink key positions. This is as real-time as it can get and very similar to how closed-loop register systems work, though more complex.

Hypotheses

There are three hypotheses proposed in this paper. One is that on-line closed-loop color control systems reduce longer-term drifts in solid ink densities. Two, shorter-term variation is reduced as well. And three, that these systems are capable of driving the press to programmed target densities during makeready more quickly and with less waste than is possible without these systems.

Equipment Used for the Experiment

A web offset press equipped with a closed-loop color control system was identified for the experiment. The press was a 40-inch, 6-color heatset press at a production commercial printing facility. Additionally, CIP3 data were used for ink-key presetting. Key components of the closed-loop color control system include the on-press module (Figure 1) and the press operator console (Figure 2) as pictured below.

Figure 1

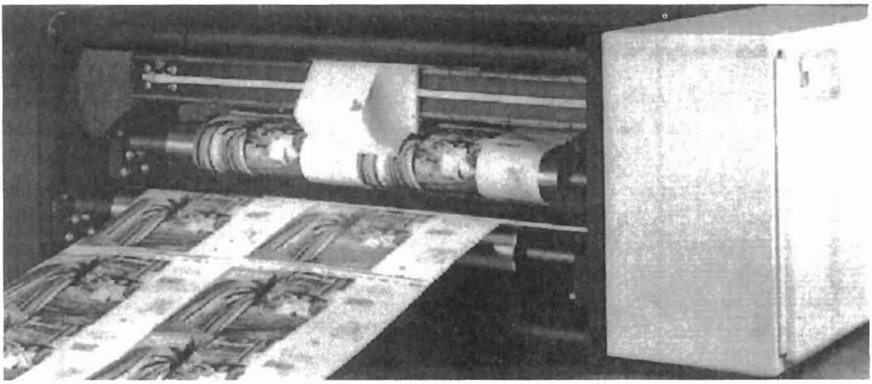
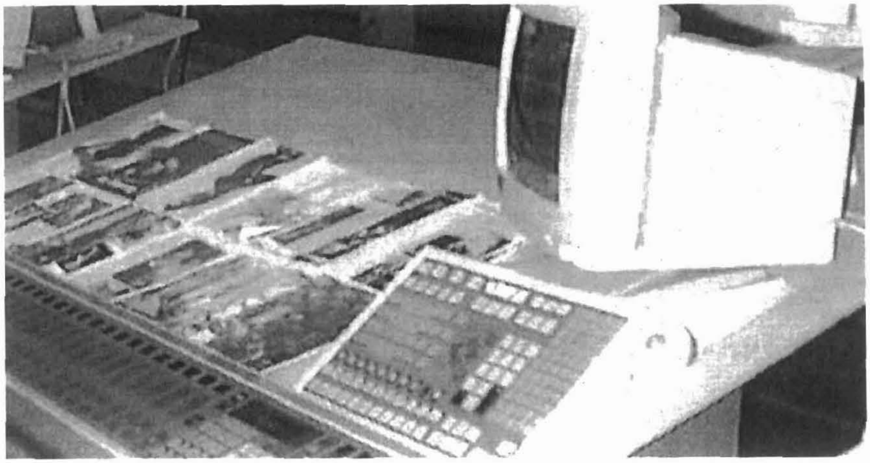


Figure 2



The on-press module, itself, contains two main devices: a video camera to locate the color bar and a spectrophotometer to read the individual patches. The color bar itself is 2 millimeters wide and spans the entire web width. Each patch is 4 millimeters in length, which typically allows for all units to be represented within one ink key width. Below are a diagram of the on-press module (Figure 3) and a close-up of the measurement head and color bar (Figure 4).

Figure 3

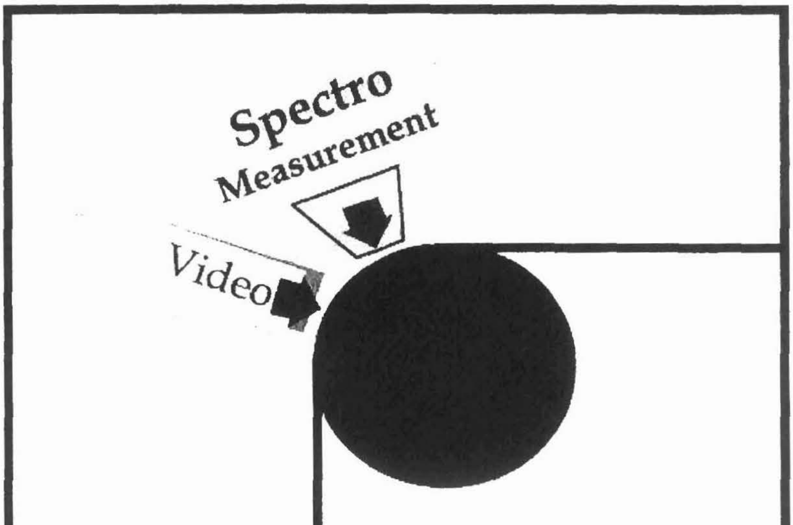
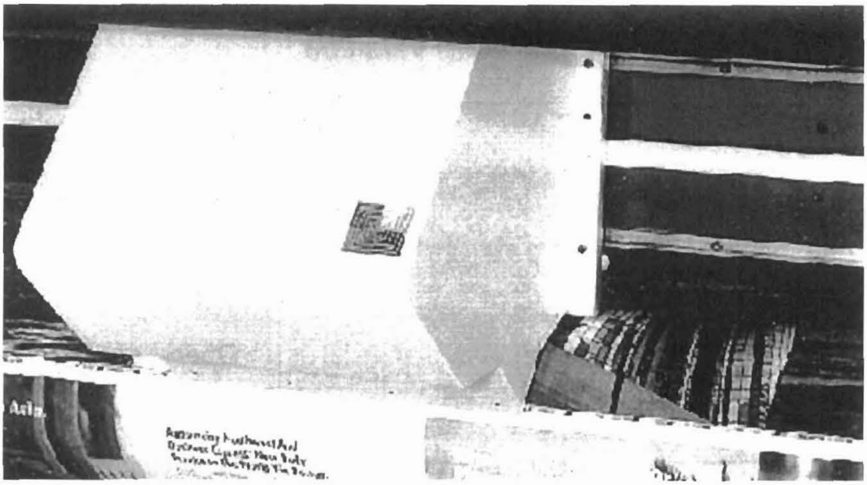


Figure 4



Within the measurement head, the video camera locates the color bar, verifies the patch to be measured, and detects any defects within the patch. The spectrophotometer verifies the color and takes the measurement. The data are then downloaded to the press operator console for display, analysis, and control.

Experimental Procedure for Variation Hypotheses

For the first and second hypotheses, data were captured by the on-line measurement system from a live, commercial web press run, and observations were made. The twenty (20) hour production job was allowed to run in closed-loop mode for roughly half the time (~10 hours). The bottom side of the web was then taken out of closed-loop mode so that changes in both long-term drift and short-term variation could be monitored. While in open-loop mode, manual adjustments to the ink keys were done and were done with the aid of automatic measurement (the on-press module took measurements, but did not control the ink keys).

Results

What follows are graphs (Figures 5-8) of each of the four process colors (KCMY) showing the run data of both closed and open-loop modes.

Figure 5

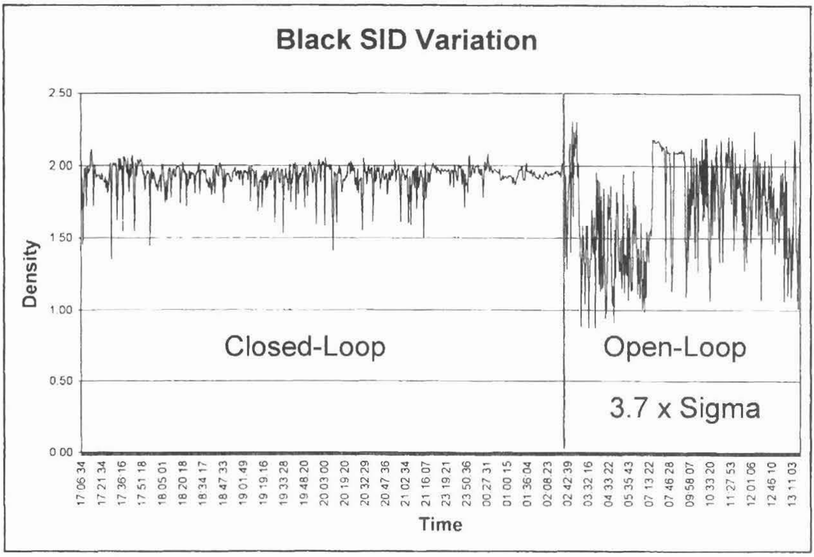


Figure 6

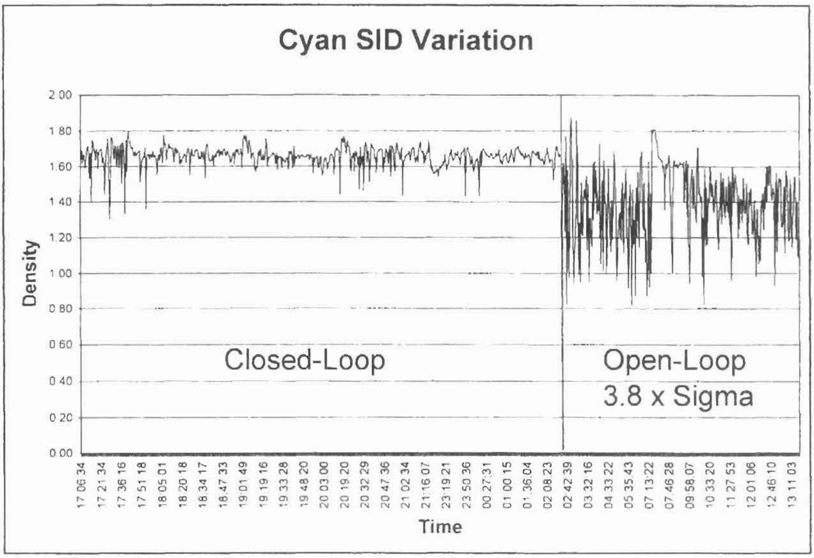


Figure 7

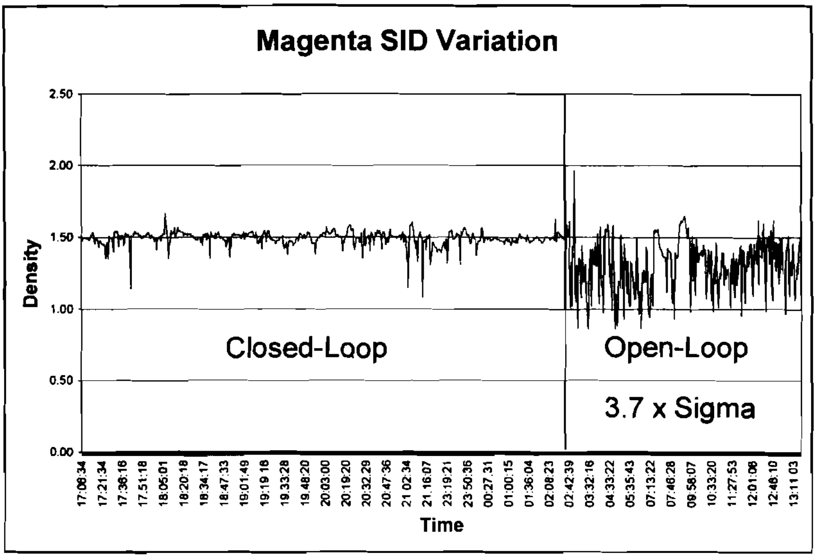
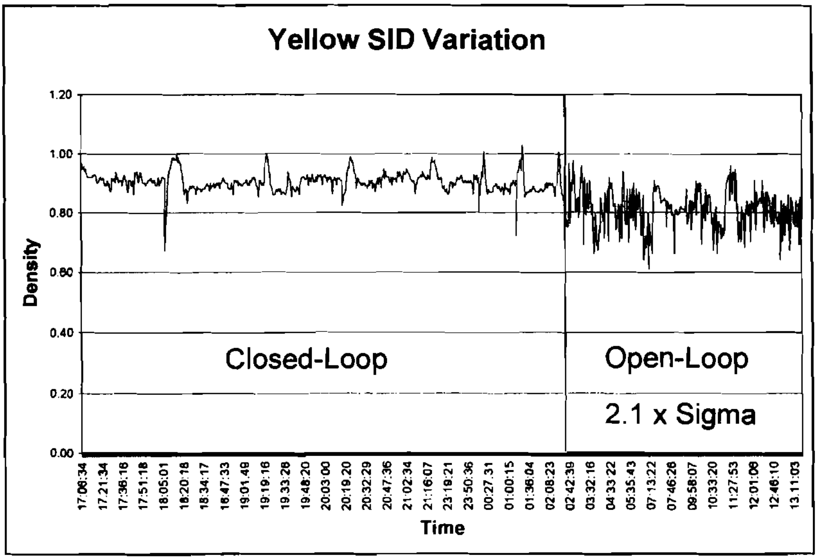


Figure 8



As can be seen, there is a very significant increase in variation of solid-ink density for each of the colors when the press was taken out of closed-loop mode. Standard deviations were calculated for each of the conditions and colors. On each graph, the amount of increase in standard deviation is indicated in parenthesis under the "Open-loop" text. For example, black showed an increase in standard deviation by a factor of 3.7, meaning there was 3.7 times more variation in open-loop than in closed-loop mode. Cyan and magenta show a very similar situation, with 3.8 and 3.7 times more variation, respectively, in open-loop mode. Yellow was less variable in both modes yielding only 2.1 times more variation in open-loop mode, though this is still significant. For each color, there was no significant longer-term drift in open-loop mode than in closed-loop, though there does appear to be some cyclical behavior in the data.

Experimental Procedure for Makeready Hypothesis

For the third hypothesis, a makeready was monitored to determine how quickly, in terms of impressions; target densities were achieved by the closed-loop color control system as opposed to the more typical manual, or non-automated, makeready procedure.

Typically, during a makeready multiple activities are worked on concurrently by multiple operators. One may work on color while another works on register. There are a variety of techniques, but regardless of how a makeready is performed, when a correction is made, be it to color or register, a certain amount of time is required to allow the adjustment(s) to take effect. Determining how long to wait can be difficult, and if not timed properly, one of two situations can possibly occur. One is when not enough time is allowed. Here, a second correction in the same direction may occur causing an "over-control" of the process and sending it beyond its intended target. A second situation may occur when the change has taken effect, yet the press runs longer until somebody determines that the change has occurred. Both conditions lead to higher waste. The point is that with automation, the inconsistent, subjective analysis of human operators is removed, and a reduction in makeready waste should be realized.

Also, oftentimes the last print attribute to reach an acceptable level is color. Registers are typically achieved well before target densities are achieved.

Results

Following are sets of charts (Figures 9-17), for each color (KCMY), showing density profiles and ink key positions of different points in the makeready. The first charts for each color are from when a scan was first possible (rough register), and the second charts (or third in the case of magenta) are from when target densities were achieved. Total number of elapsed impressions is noted on each.

Figure 9

Black - First Scan of Color Bar

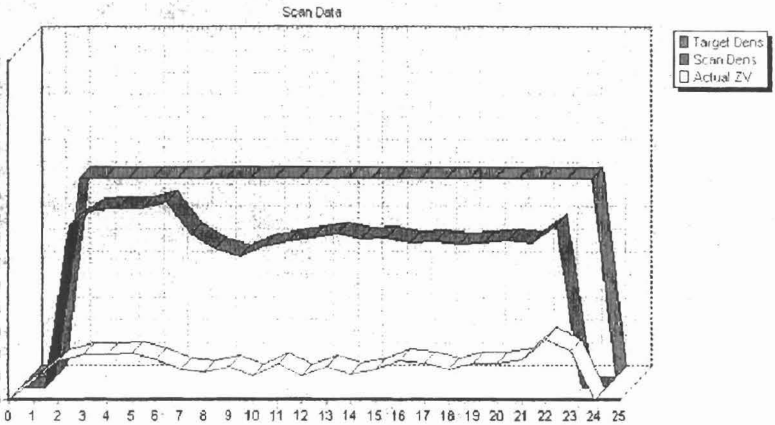


Figure 10

Black - at Target Density, 1,026 Impressions

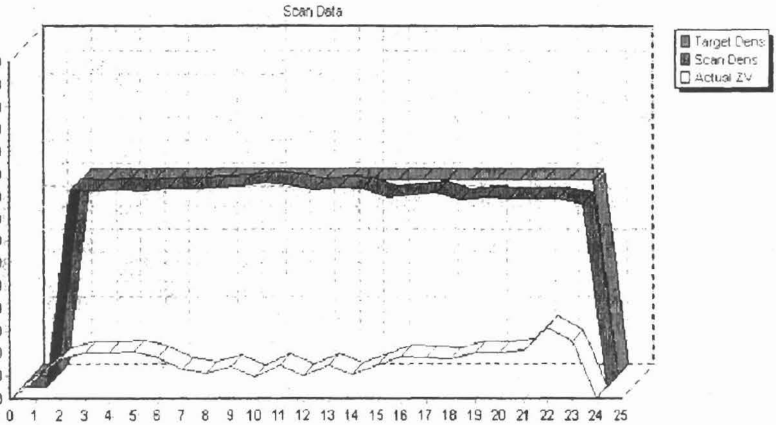


Figure 11

Cyan - First Scan of Color Bar

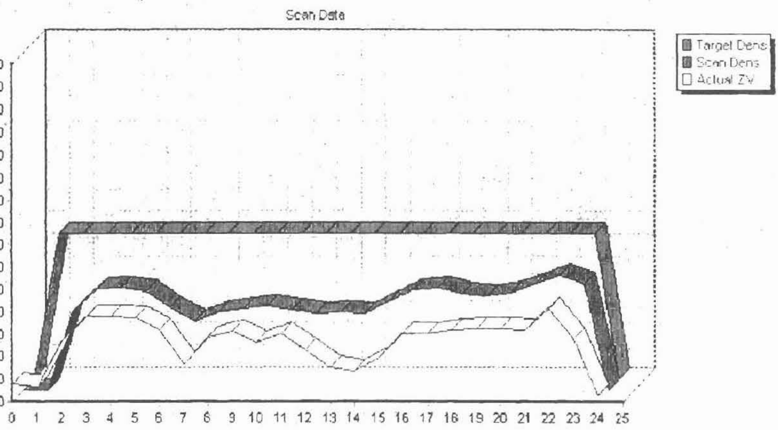


Figure 12

Cyan - at Target Density, 1,779 Impressions

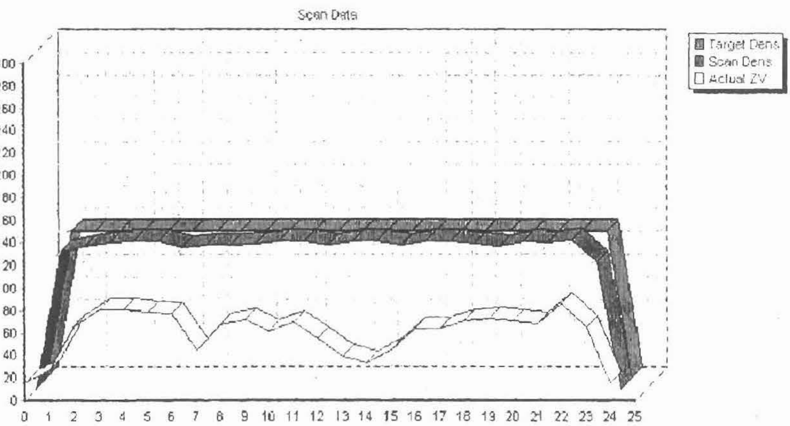


Figure 13

Magenta - First Scan of Color Bar

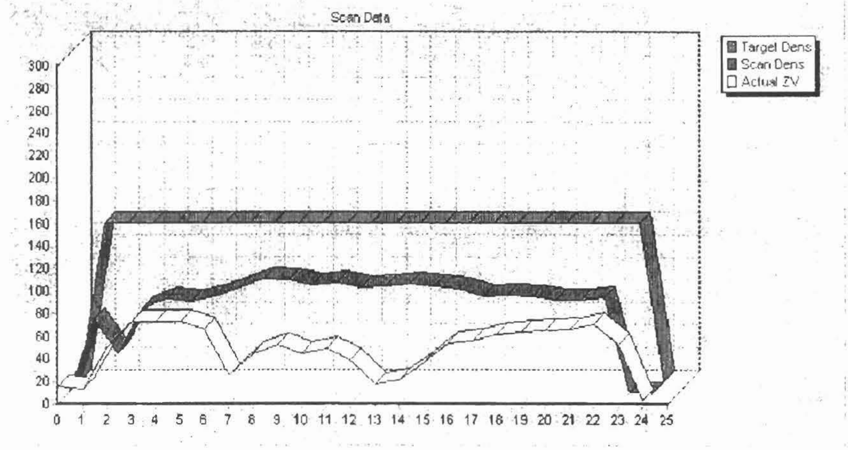


Figure 14

Magenta - Intermediate Result, 1,106 Impresions

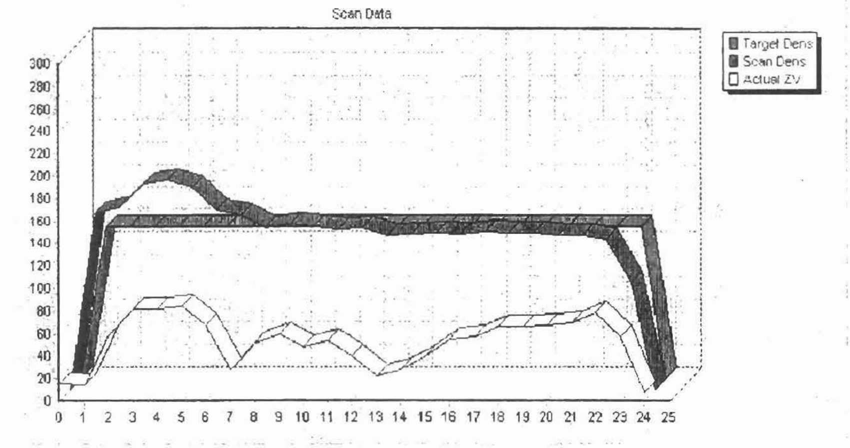


Figure 15

Magenta - at Target Density, 2,304 Impresssions

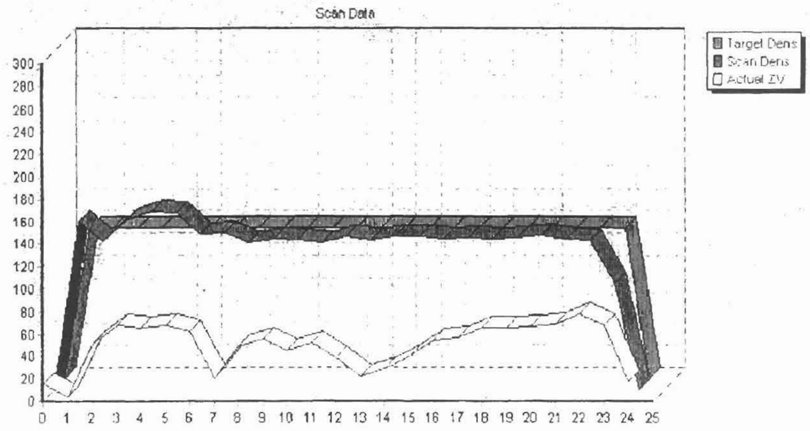


Figure 16

Yellow - First Scan of Color Bar

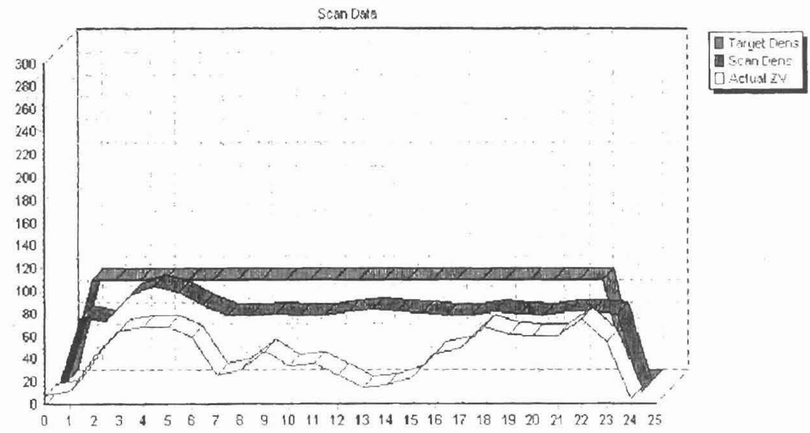
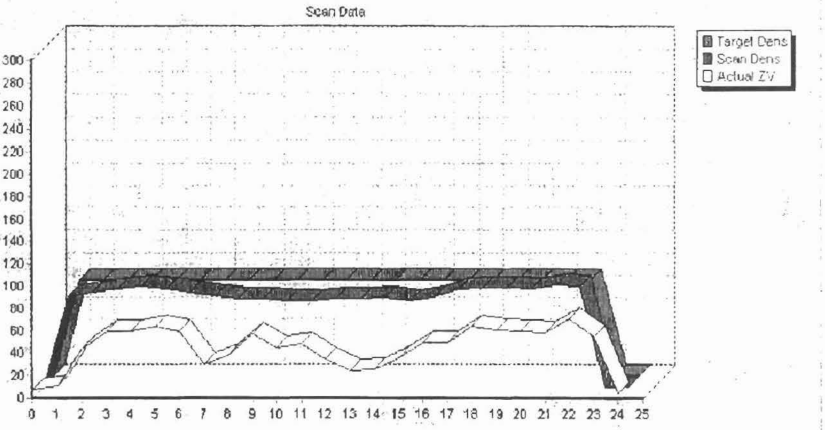


Figure 17

Yellow - at Target Density, 2,589 Impressions



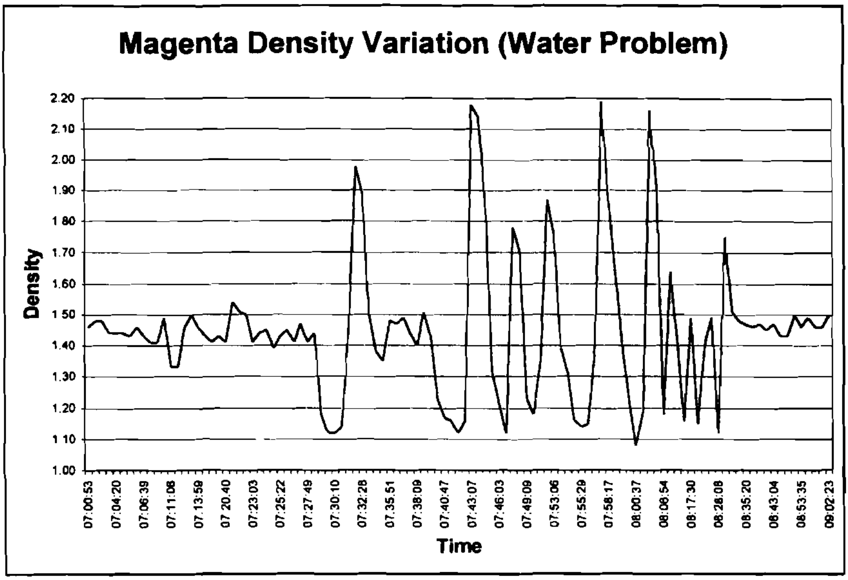
Each chart show the profile of the web (the x-axis) and contains the target densities (the top flat line), the actual density profile (the line below the target line), and the actual in key positions across the web (the bottom line). The y-axis represents density (except for the ink key position data). As can be seen, in each case the closed-loop color control system drove the press to target densities in short order, much faster than could be achieved manually. It should be noted that during this "automatic" makeready, no manual adjustments to the ink keys were made, and the operators were working strictly on ink and water balance (sweeps), register, cut-off, and fold.

In the case of magenta, there was an "over-shoot" of the ink keys on operator side of the web (left side of the chart), for some reason, which took some time for the density to drop, which required more impressions to settle the density down to the target range. The other three colors, on the other hand, were brought to target densities very quickly and effectively without any issues.

Unanticipated Finding

During the course our trials, we observed a situation where the closed-loop color control system picked-up on a press problem that manifested itself in excessive solid ink density variation on the gear side only. Specifically, what was observed was a sudden increase in magenta SID variation, whose cause was an ink and water imbalance. Below is a graph (Figure 18) of the data.

Figure 18



As the graph shows, the magenta SID was in control, but suddenly became erratic. Upon further investigation it was found that the magenta metering roller in the dampener had lost its setting and required a skew adjustment. When this was done, the SID settled down to its normal stable level under closed-loop.

This raises an interesting point about how on-line closed-loop color control systems can also be utilized as indicators of when something goes wrong in the process that is manifested in the form of solid ink density variation. Granted, the system will not tell you what is wrong, however it will “raise a flag” and alert the operators that the process has gone out of control. At that point, good troubleshooting and process understanding will be necessary.

Conclusions

It has been shown that the first hypothesis is “semi-true”, meaning that though longer-term drifts appear to be better controlled by the closed-loop color control system, operators also correct drifts (in open-loop mode), though not as quickly and with a more cyclical pattern in the data.

The second hypothesis has been shown to be strongly true, that closed-loop color control greatly reduces shorter-term variation over open-loop mode.

Finally, it has been shown that the third hypothesis is true, that closed-loop color control systems do, in fact, drive the press during makeready to target densities, and do so more quickly than by manual methods and without any operator adjustments to the ink keys. In fact, feedback from users indicates that acceptable color is often achieved before all registers.

Opportunities for Future Study

Though the findings in this study are impressive and very promising for the future of automated color control in offset printing, there is an opportunity and need to sample and analyze a larger population of jobs, both in terms of variation and for makeready performances, to further support these findings. Furthermore, work should be done to analyze other printing attributes such as dot gain, gray balance, and color variation using colorimetric data. Though these systems tout closed-loop ***color*** control, and the system used for this paper utilizes spectrophotometry as the color measurement technology, they are currently deriving densities from either spectral or RGB data and (currently) only reacting to solid ink densities. As is well known, variations in dot gain, trap, register, etc. all affect color, and simply controlling SID in an automated fashion, though a great advancement, does not guarantee control of color. Work is underway by most of the vendors to monitor other printing attributes to control color more effectively. Solid ink density is just the first logical step in the evolution and is the current chief attribute used in most off-line scanning and manual measurement systems. The future is bright for closed-loop color control and its users, and one-day, it will be as commonplace on presses as automated register controls are today.