MODEL-BASED INK KEY PRESETTING FOR OFFSET PRESSES

Chia-Lin Chu* and John C. Seymour*

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Abstract: The purpose of this study is to develop an ink key presetting system which can analytically preset ink keys and ratchets and can thus greatly shorten the make-ready time. A steady-state inking system model, comprising the roller train, vibrator, overall system gain, and density-thickness relationship, was developed for this purpose. In the presetting process, the plate coverage is first estimated from a digital plate file or a plate scanner. Via the inking system model, ink key openings are further estimated. Finally, ink keys and ratchets are set automatically through an electronic interface. In addition to being a standalone tool, this presetting system will be used to provide the initial settings and ink consumption information for an on-going closed-loop color control project.

Introduction

The job of a preset system is to preset ink key openings for a printing job such that the inking levels are close to required amounts. Proper ink key presetting could shorten the make-ready time and thus reduce paper, ink, and labor waste.

Ink key presetting products have been available in the field for many years (Murray, 1976, Nishida, 1991, Maier, 1992 and Toyama, 1996). These products normally include an optical plate scanner where plates are scanned for coverage for each ink key zone. Plate coverage is the ratio of the inked area to the plate area. Combined with some empirical parameters associated with the characteristics of the press, ink, type of jobs and paper, the information is then used to preset the ink key openings. These empirical parameters are usually learned from consistent usage of the presetting system. The more consistently the system is used, the better the presetting. Several different sets of parameters should be acquired for different types of printing jobs, especially for different coverages.

Alternatively, pressmen commonly eyeball the plates or proofs to roughly preset the key openings or simply preset the key openings uniformly across the web to a

*Quad Tech International, N64, W23110, Main Street, Sussex, WI 53089

level depending on the overall coverage. These guesses, although better than nothing, often generate very poor initial printing and result in a long make-ready time.

More recently, computer-to-plate (CTP) has become more popular in the field. The plate coverage can be easily and more accurately obtained. This new advancement and the fact that the existing ink key presetting products are not quite satisfactory inspired us to work on a new generation of ink key presetting systems. It should be able to preset ink key openings, water and ratchet settings automatically for various types of jobs, inks and papers without much of the pressmen's input. This presetting system is based on an inking system model which transforms the plate coverage to the ink supply. The model is a steady-state inking system model, which includes the effects of the roller train, the overall gain, and the relationship of density and ink film thickness on paper.

Modeling the inking system

After studying literature on inking system, performing experiments, and actually running numerous press tests, we finally convinced ourselves that a model for the inking system is absolutely necessary for such a new generation of ink key presetting systems.

There have been quite a few papers on modeling parts of the inking systems in the literature (Chou and Bain, 1996, Guerrette, 1985, Mill, 1961, MacPhee, 1995, Scheuter and Rech, 1990). However, none of them seems to have included the complete inking system such that it can readily be implemented for ink key presetting. Nevertheless, these research results provided an excellent starting point for attacking the problem.

Roller Train

The complete roller train (from the ductor roller to the paper) can be modeled based on the assumption of the continuity of ink film thickness (Guerrette, 1985). Two equations (Eq. 1 and 2) can be derived at each nip point between rollers (Figure 1).

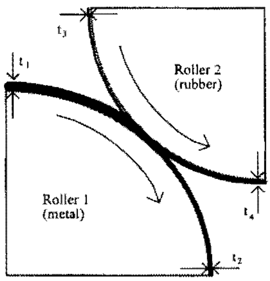

Figure 1. Nip point between two rollers. Ink is transferred from Roller 1 to Roller 2.

$$t_2 = s_m(t_1+t_3) \qquad (1)$$

$$t_4 = (1-s_m)(t_1+t_3) \qquad (2)$$

with,

t_n: ink film thickness on roller, n=1 to 4,
s_m: split ratio for metal roller.

Where s_m is an ink split ratio between a metal roller and a rubber roller. This split ratio may be different for each pair of rollers, but for simplicity, we will treat them the same throughout the roller train.

This pair of equations is sufficient to describe the ink film thickness on each roller surface except for the plate cylinder, where the plate has the image. For the areas containing solid coverage, the nip equations remain the same; for areas without coverage, the plate takes no ink and all the ink returns to the form roller. The nip equations are then shown in Eq. 3 & 4 (refer to Figure 2).

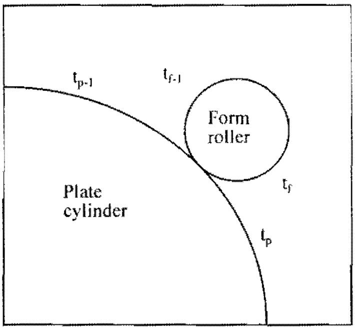

Figure 2. Nip point between a form roller and the plate cylinder. Ink is transferred from the form roller to the plate.

$$t_p = s_p(t_{p-1}+t_{f-1}) \qquad (3)$$

$$t_f = (1-c)t_{f-1}+c(1-s_p)(t_{p-1}+t_{f-1}) \qquad (4)$$

with,

t_{f-1}: ink film thickness on form roller before nip point,
t_f: thickness on form roller after nip point,
t_{p-1}: ink film thickness on plate before nip point,
t_p: thickness on plate after nip point,
s_p: split ratio for plate,
c: plate coverage.

Figure 3 illustrates a complete roller train configuration for the lower printing unit of Harris M1000B. Following the conservation of ink, a constraint between the ink supply to the first roller and the ink on paper should be maintained, as illustrated in Eq. 5.

$$t_0 - t_{-1} = ct_{29}, \qquad (5)$$

with,

t_0: ink supply from the ductor roller to the roller train,
t_{-1}: ink returned to the fountain,
t_{29}: ink film thickness on paper.

With these basic nip equations, a set of simultaneous equations can be formed and solved for ink film thickness at each nip point of the roller train.

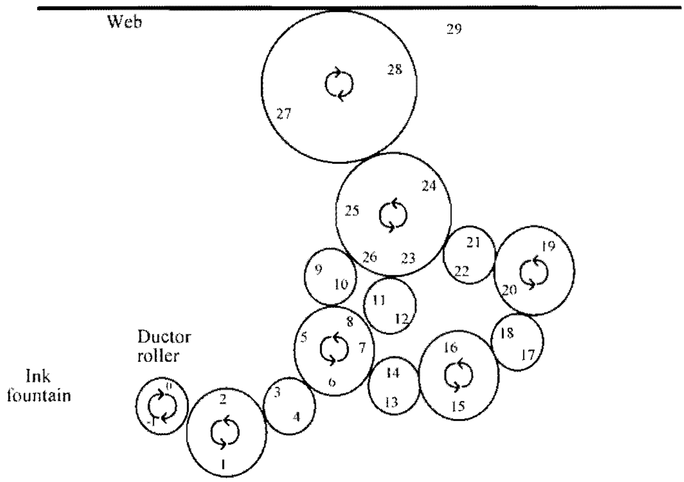

Figure 3. Roller train of the lower printing unit of Harris M1000B. Numbers label the surfaces carrying different ink film thickness. Arrows indicate the direction of rotation.

An assumption of a 50% split ratio, which has been assumed in several papers (Guerrette, 1985, MacPhee, 1995, Chou and Bain, 1996), is used for all nips. The solution of the simultaneous equations gives the ink film thickness at each point on the roller train of the Harris M1000B press (Seymour, 1996a). In Figure 4, a family of curves for ink film thickness at various coverages is shown. It shows that if the thickness on paper is a desired 1 unit, then the ink feed to the first roller has to be about 3 to 7 units depending on the coverage.

The relationship between ink feed at the ductor roller and coverage, as summarized in Figure 5, fits very well to a straight line (the solid line).

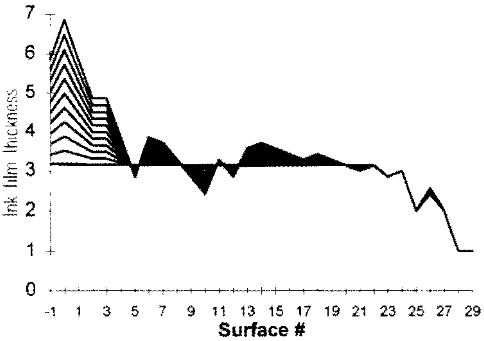

Figure 4. Ink film thickness at various points of the roller train. Each trace corresponds to different coverage from 0% to 100% in ascending order at Nip 1.

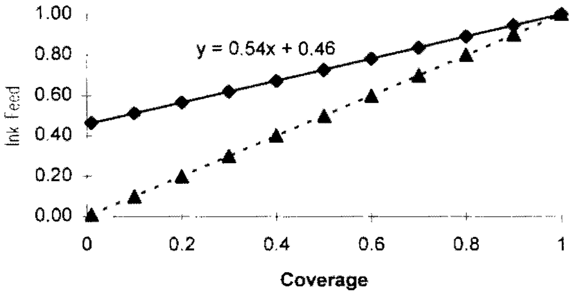

Figure 5. Ink feed versus plate coverage. Solid curve: model predicted; dotted curve: conventional paradigm.

This relationship indicates that an ink feed of 46% of that of full coverage is needed for even a 0% coverage! This contradicts more intuitive thinking that no ink is needed if there is no coverage as illustrated by the dotted curve in the same graph. However, as we have analyzed before, the difference of the ink supply and ink return has to equal to the ink on paper to conserve the ink. The key opening is related to the ink supply and not to the ink consumption.

In order to print uniformly across the web, the ink film thickness has to be maintained uniformly across, even if there is only a tiny dot to be printed in a certain key zone.

A kitchen sink model is a good analogy to a conventional paradigm of how a roller train works. As illustrated in Figure 6, the ink flows from the faucet and all of it is "consumed by the drain" that is transferred to the paper. According to this model, the ink key should not be opened if there is no coverage. But this is incorrect because it ignores the fact that the ink is not only transferring forward to paper, but part of the ink also transferring back to the fountain. It is the net ink supply that meets the principle of conservation of ink.

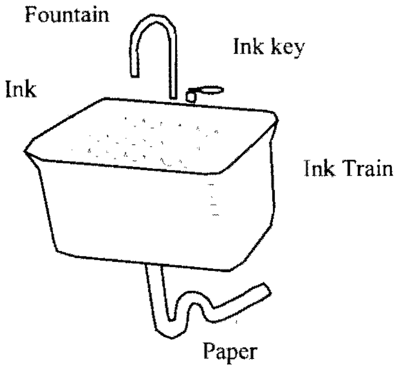

Figure 6. Kitchen sink model for roller train.

The sensitivity of the split ratio, *s*, was calculated at 0.2, 0.5 and 0.8 for ink favoring metal rollers, equal favoritism and ink favoring rubber rollers, respectively. The results (Fig. 7) indicated that the assumption of a fixed split ratio of 0.5 does not drastically effect the results.

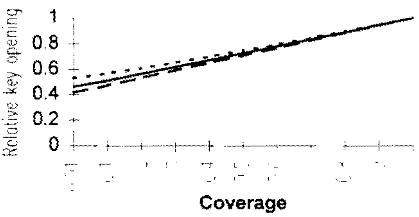

Figure 7. Relative ink key opening vs. coverage with various ink split ratios. Solid line: s=0.5, dotted line: s=0.8, dashed line: s=0.2.

Vibrator rollers

In addition to the above one dimensional nip equation analysis, there has also been studies on two dimensional modeling reported (MacPhee, 1995, Chou, 1996). Unfortunately, the effects of vibrators were not included.

There were some conjectures about ink behavior in the roller train with vibrator rollers. Some thought that the ink flows automatically to the zones where ink is needed to quite a few key zones away; other proposed that the side pressure from the ink in neighboring zones or the back pressure from limited ink take-up in low coverage areas governed the distribution of ink. Either saying would complicate and thus discourage the modeling of the vibrator's effects.

To clarify the puzzle, we conducted a test on an M1000B press. We disabled the vibrators of a printing unit and closed all ink keys except the key at the center (Key 13). The plate design (Figure 12) included a long solid bar and was sandwiched by a pair of 90% halftone bars. As shown in the solid curve in Figure 8, the optical density of the solid bar was about 2.1, while the densities for the neighboring halftone bars were about 0.15. It clearly demonstrated that ink did not flow to the neighboring zones just because of the demand of coverage or roller pressure. Instead, ink is distributed to neighboring zones exclusively by the forceful motion of the vibrator rollers. Note the small round-offs at the borders which were due to the fact that the vibrators could not be totally disabled. A minimal travel of 0.25" was still in effect. The up to 0.6 density at Key 11 was due to the combined effect of a minimal ink key opening for lubrication and the fact that the zonal coverage was only 10% there.

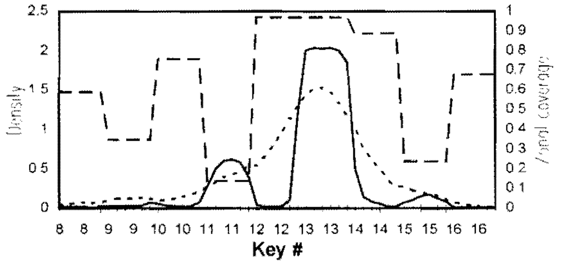

Figure 8. Ink distribution with vibrators on (dotted curve) and off (solid curve). The dashed curve is zonal coverage.

Enabling the vibrators again, which had a travel of 1.5", we recorded the densities in the same region as shown in the dotted curve in Figure 8. The reason why the curve stretched out for at least two to three key zones each side (3" to 5") was because that there were four vibrator rollers in a M1000B printer. Note that there was a skew in the shape of the curve. The skew was again caused by the differences in coverages. After correcting for zonal coverage with the roller train model, we obtained a more symmetrical ink spread.

With these findings, we adopted a modified and normalized version of the dotted curve as the vibrator model (Seymour, 1996b). A 24 by 24 matrix, V, was formed as the vibrator matrix.

Modeling other parts in inking system

In order to preset the ink keys for known plate coverage, the rest of the parts of the inking train need to be modeled as well. These parts include the ink key controller (color console), ink keys, ink fountain roller (ball), ratchet (stroke), and ductor roller. The relationships among all these elements were intuitively approximated to be linear and have been mostly verified by us in experiments.

First, let's address the relationship between the ink key controller and the ink key opening. With an electronic signal from the color console, the ink key actuator drives the key blade in and out, thus controlling the key opening. The key movement is recorded through a linear potentiometer and displayed on an LED display on the color console. This relationship can be modeled with a linear gain and an offset. We have actually measured the ink key openings with a feeler gauge at various display levels as shown in Fig. 9. Note the measurement error was quite significant because most of the keys were more or less crooked and the step size of the feeler gauge is rather coarse. Also when the LED display is set to 0%, there is still a minimal key opening for lubrication purpose. With these possible error sources, we concluded it to be a linear relationship.

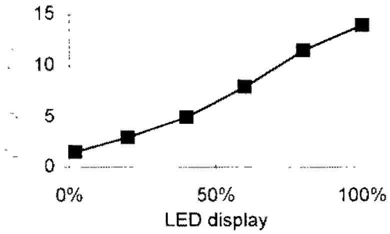

Figure 9. Ink key opening versus LED display on color desk.

We have also measured the relationship between the key opening and ink film thickness on the ink fountain roller with a "laser displacement sensor" (Omron Z4M-W40). This sensor uses a small laser spot (less than 1 mm in diameter) with triangulation to measure relative differences in height. The instrument has a resolution of 1.5 μm (0.06 mil). Again, the results for cyan, magenta, and yellow inks suggested a linear relationship, although with different slopes, as shown in Figure 10. Data for the black ink was not available because not enough reflection could be detected by the instrument. But a linear relationship with a different slope can be expected.

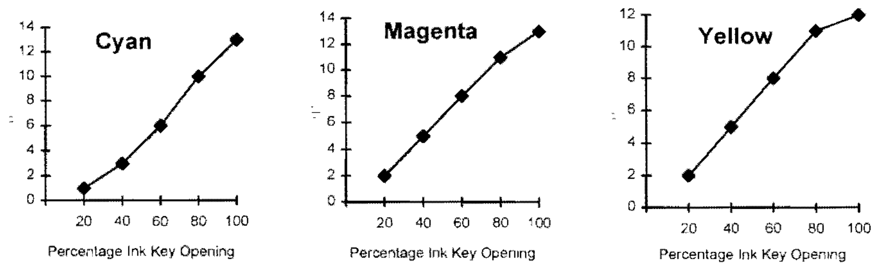

Figure 10. Relationship between ink key opening and ink film thickness on ink fountain rollers.

Errors were also expected in these measurements, since the ink fountain rollers were grooved and thus added some noise in the data.

No measurement of ink film thickness on the ductor roller has been attempted due to the fact that it was not quite feasible to do so while the press was running.

However, it seems not unreasonable to assume the relationship of the ink film thickness between the ink fountain roller and the ductor roller to be linear.

Finally, the ratchet setting linearly controls the angle that the ink fountain roller rotates in each stroke. The angle determines the amount ink transferred to the ductor roller. Again, this relationship seems not unreasonably to be assumed as linear. With this, the ink film thickness supplied to the rollers is proportional to the product of the ink key opening and the ratchet setting.

Although measuring the gains of some parts of the inking system is not quite accurate or not quite feasible, we can still complete the model if the overall gain of the inking system can be measured. This approach will be discussed in the following few paragraphs.

Density vs. Ink film thickness

The relationship between ink film thickness and density has been studied and formulated in literature. Compared to measuring ink film thickness on paper, measuring density is much more accurate and convenient. For simplicity, we adopted the equation proposed by Tollenaar and Ernst (1962).

$$d = d_s(1 - e^{-kf}) \tag{6}$$

with,

d: density,
d_s: saturation density,
k: a constant,
f: ink film thickness.

Overall model

With all these models for the parts of the inking system, we can now construct an overall inking system model. The film thickness on the paper is then the product of the unknown linear gain (***g***) and a known *ink film thickness equivalent* (***t***) based on the model.

$$f_i = gt_i = \frac{gr}{(0.46 + 0.54c_i)} V_i(I - B) \tag{7}$$

with,

i: zonal index, from 1 to 24,
f_i: zonal ink film thickness,
g: the gain,
t_i: zonal ink film thickness equivalent,
r: ratchet setting,
c_i: zonal coverage,
V_i: zonal vibrator vector (row vector),
$I - B$: zonal key opening minus its offset, a vector for all keys.

Substituting f_i into Eq. 6, we obtain

$$d_i = d_s(1 - e^{-kgt_i}) = d_s(1 - e^{-ht_i}) \tag{8}$$

with,

h: a combined constant of g and k,
d_i: zonal density,
d_s: saturation density.

Expanding Eq. 8 further, the overall equation of the inking system model is then

$$d_i = d_s(1 - e^{-\frac{hrV_i(1-B)}{0.46+0.54c_i}}) \tag{9}$$

Test for press gain and saturation density

The press gain and the saturation density can be determined for each ink in a press test with ratchet setting at various levels through a least-square fit to Eq. 9, and thus complete the model. Solid ink densities for each ratchet level are measured and the ink film thickness equivalent **t**'s are calculated. A curve fit for determining the press gain and saturation density for the black printer is shown in Figure 11.

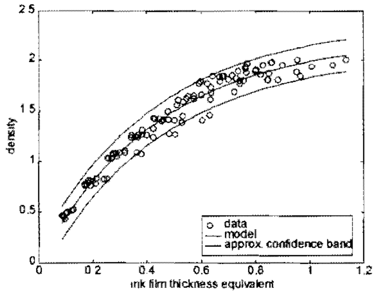

Figure 11. Curve fitting for the saturation density and press gain for black printer.

Presetting

With this model, ink key presetting can be readily achieved. Presetting involves calculating the plate coverage for each ink key zone and transforming it to the zonal ink supply by implementing the model backwards.

Plate coverage can be accurately calculated with a CTP file simply by summing together the image area for each key zone. Optical plate scanners can generate quite accurate coverage information, too, with plate calibration, uniformity correction, and perhaps geometrical corrections.

The equation for ink key presetting can be reversely derived from Eq. 9.

$$r(I-B) = -\frac{1}{h}V^{-1}\begin{bmatrix}(0.46+0.54c_1)\ln(1-\frac{d_1}{d_s}) \\ \ldots \\ (0.46+0.54c_n)\ln(1-\frac{d_n}{d_s})\end{bmatrix} \qquad (10)$$

with,

r: ratchet setting,
$I - B$: zonal key opening minus its offset, a vector for all keys,
h: a combined constant of g and k,
V^{-1}: inverse vibrator matrix,
$c_i,,c_n$: zonal coverages,
$d_i,,d_n$: zonal densities,
d_s: saturation density.

A proper ratchet level is then chosen such that the range of the ink key opening is within a proper range. The keys and ratchets are then preset through electronic interface to the color console.

An example of presetting

A black plate with 24 bars corresponding to the 24 ink key zones and the corresponding zonal plate coverage are shown in *Fig. 12*. The solid bar at the bottom of the plate can be used for density measurement for each key zone.

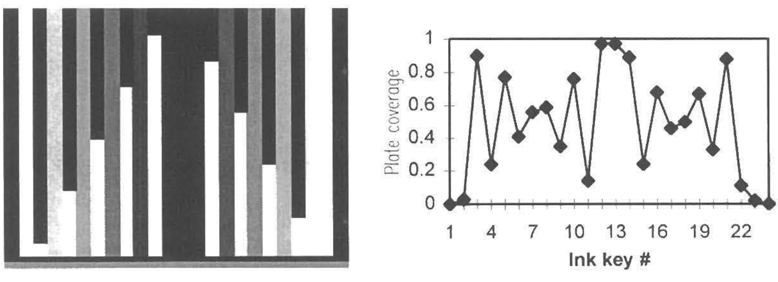

Figure. 12. The test plate (left) and plate coverage (right). Zero coverage for Key 1 and 24 was due to the narrower web width.

The ink key openings were manually adjusted such that a target density of 1.7 was approximately achieved across the web. The key openings were recorded electronically and were referred to be the *actual key openings* later on. Ratchets were set to various levels for various ink film thicknesses and densities on paper.

To demonstrate the presetting with the only test data set available, we used the data from Key 13, with almost 100% coverage to determine the inking system gain and the saturation density with Eq. 9 and Figure 11. Then we employed these numbers to determine the ink key openings and ratchet settings for all the rest of the keys, based on the model, i.e., Eq. 10.

As one can see that both settings are essentially at the same level regardless of the coverage. The calculated key openings are plotted against the actual key openings in *Figure 13*.

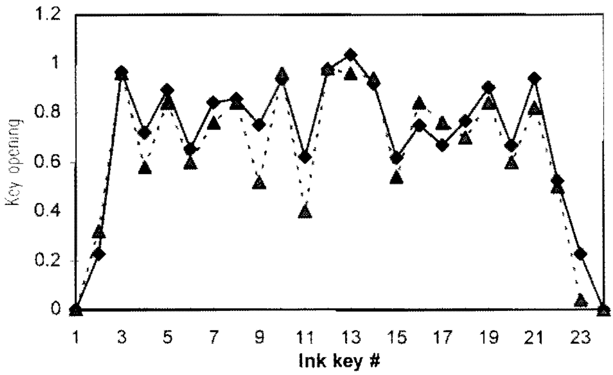

Figure 13. Ink key presetting: model (diamonds) vs. actual (triangles).

The major difference between the two sets of data is that the calculated presetting is less peaked. This is attributed to the fact that the inversed vibrator model was not taken into account in the presetting. In other words, the V^{-1} was not implemented in Eq. 10.

Similarly to the pressmen's practice, the edge ink keys were set to fully closed due to the fact that the web was narrower than the plate. For these key zones, no ink supply is necessary for the purpose to maintain a minimum ink film thickness, only for lubrication.

The web width varies depending on the requirement of a job. Although a minimal key opening of 46% of full coverage setting is required according to our earlier argument, this is not true beyond the edges of the web. Only a fraction of ink is needed there.

Discussion

This model-based ink key presetting method provides an analytical way to uniquely preset ink key openings and ratchet settings. The preliminary results described above have demonstrated that this is a promising approach. Unfortunately, validating press test results of the ink key presetting was not available in time for this paper.

The model was simplified for preliminary results. The goal was to establish a model which includes only the most essential parts to demonstrate that an improved scheme for ink key presetting is possible. Other factors which should be included in the model include the effects of ghosting, press speed, various types of papers, and the non-linearity of film thickness vs. low ink key opening, as well as physical dot gain.

Another factor that has been ignored in this paper is the dampening system, which has an important effect on printing. A proper water presetting is also desired along with ink key presetting.

Although this presetting system does not require consistent usage, it does need the fountains to be maintained in calibration. A typical keyed ink fountain, however, has a drawback of occasionally getting stuck. A convenient and effective action practiced by pressmen is to unstick the key with a screwdriver. As a result, the fountains typically run in an un-calibrated mode. However, in order to obtain accurate gain constants and presettings, fountains must be maintained in calibration. A full scale calibration may not be feasible due to the extensive work; but a minimum zero-checking of ink film thickness on ink fountain rollers and the ink key controller is absolutely needed. Preferably, a non-stuck precision fountain is desired for assuring satisfactory and consistent presetting.

As indicated in *Figure 13*, the presetting was not as peaked as the actual setting due to the fact that the vibrator effect was not included in the presetting. The exact presetting is not absolutely necessary, however, if the presetting is followed by an on-line closed-loop color control.

Therefore, our ultimate goal for developing this ink key presetting system is to deploy it jointly with the on-line closed-loop color control system we are developing. The color control system will take over the control of the inking system at the good starting point the presetting system has achieved, and will rapidly fine-tune and control the color, producing quality and consistent printing in minimal time.

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