A METHOD FOR MEASURING INK-JET WICKING USING A DOCUMENT SCANNER AND A PERSONAL COMPUTER

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A fast, simple, low-cost procedure for evaluating ink-jet print quality.

THE NEED FOR A TEST OF PAPER DESIGNED FOR INK-JET printers came up during a conversation with a mill quality-control manager about two years ago. At the time, the quality lab was using a conventional scanner/PC-based dirt-count system, and the manager expressed a wish for an ink-jet wick and bleed test that was as repeatable, easy to perform, and rapid as the dirt counter.

Upon first considering the task, it seemed that simply measuring the specific size of a printed pattern containing a large number of dots would indicate the degree of wicking present. The reasoning was that if the size of the dots varied from grade to grade (or from run to run) while all other variables were held constant, the variation was probably due to differences in the paper. The dot pattern was selected because a small dot the size of a 12-point bold period (Arial font) has a high periphery in relation to its area, thus offering the maximum opportunity for wicking.

This hypothesis was tested by printing a pattern containing more than 1100 dots on a mix of grades, measuring the dot size, and comparing the results with a visual inspection. The test did not work well enough to define wicking in all cases. Dot size alone was not a satisfactory criterion for evaluating wicking, since it was often difficult to distinguish between dots with ragged edges and dots with sharp edges. The dot pattern also taxed the print engine's ability to print each dot uniformly.

A re-evaluation of the technique for measuring dot size led to an analysis of the entire pattern as a single entity rather than as discrete parts. It was reasoned that the overall count of those picture elements (pixels) making up the printed image or stained by the wicking ink would be a measurement of the overall pattern size. It was also reasoned that (a) the average of those same pixels would be an indication of the level of holdout and (b) the raggedness of the printed pattern edge would be a function of the standard deviation of the pixel gray-scale value (GSV) frequency distribution.

A closer examination of the scanner and PC disclosed many less obvious variables that would affect the test in addition to the interaction between ink and paper:.Things like the scanner bulb warming time, sheet opacity, variations in the sheet flatness (cockle) and formation, and the printer engine (ink-jet print head, motor, and drivers) presented additional opportunities for variation. Each of these was examined and a means of control established.

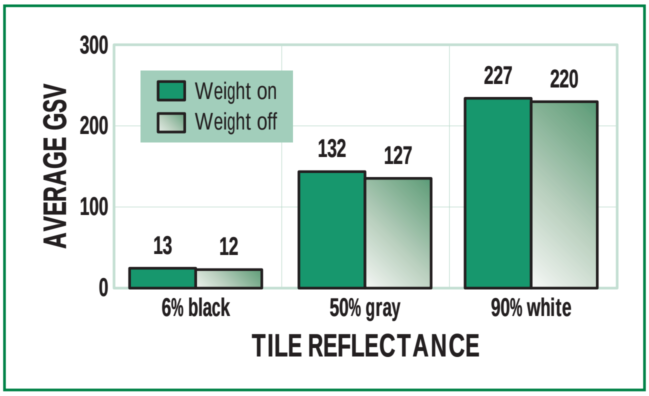
FIRST EFFORTS TO REDUCE VARIATION IN THE METHOD

Apparatus

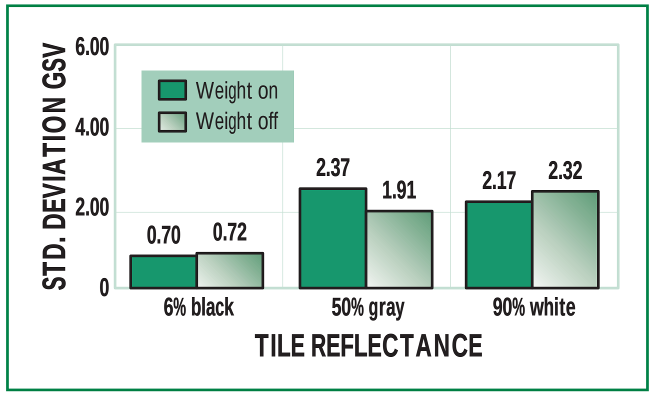
Apogee Spec*Scan dirt count software (Version 1.2.16) was used inside a system with a 600-dot/in. (dpi) (42-µm-diam. pixel) document scanner (Hewlett Packard 3c model) and a four-color, two-cartridge printer with drivers (an HP 660c).

Weight on scanner lid

A set of three calibration "tiles" was supplied with the dirt counter. These were used to test the effect of placing a 3.78 kg (8.3 lb) weight (1-gal jug of water) on the scanner lid. The "tiles" are carefully controlled 153 mm × 153 mm (6 in. × 6 in.) plastic film, each with a different reflective value (6% black, 50% gray, and 90% white). The reflective surface of the tiles is uniform and light stable.



1. Average GSV for calibration tiles with weight on and off



2. Standard deviation of GSV for calibration tiles with weight on and off

Reflectance	With weight	Without weight
50% gray	36	36
6% black	18	18
90% white	18	18

I. Number of scans run on each calibration tile

As summarized in **Figs. 1 and 2**, the test was run under two conditions: with and without the weight. The data for each scan were automatically recorded and stored in memory by the software. Scans were run in groups of six, and the groups were spaced at least 30 min apart to permit the scanner to cool between tests. The software then warmed the scanner bulb 10 min before running another group of six consecutive scans and recording the data for each scan. The test data charted are for all scans run as separate tests, regardless of the grouping. The total scans (in groups of six) run for each tile are shown in **Table I**. The 50% gray tile was used to determine the sensitivity of the test and how many scans were necessary to get good repeatability.

Since the software has the ability to record and count each pixel in the image area by its GSV, no measurement threshold was used. The scans were run at 600-dpi resolution. The pixel GSV data from each scan were then sorted by frequency and analyzed using the descriptive statistics resident in the dirt counter software.

As shown in Fig. 1, the weight on the scanner did appear to have an effect on the average GSV by raising the apparent overall reflectivity in all cases. The standard deviation of the GSVs for each pixel also was affected by the weight, but the response in this case was not uniform, as seen in Fig. 2. It is probable that at 600 dpi, the scanner is able to pick up detail in the gray emulsion coating that is lost when the weight is removed. From the data, the black and white tiles appear have a more homogeneous coating than the gray. Clearly, putting the weight on the scanner lid affected the measurement of GSV reflectivity. Overall, the weight increased reflectivity and seemed to reduce the variation in the pixel GSV measurement in most cases.

This same test was then applied to a sheet of sized uncoated and another coated sheet, both of which are commercially available paper advertised as ink-jet premium. A total of 18 scans (three groups of six scans) were carried out for each sheet with and without the weight on the scanner lid. The groups were spaced more than 30 min apart, and the scanner bulb was warmed 10 min before each test group. There was no image printed on the sheets, and no measurement threshold was set. **Figure 3** shows there is clearly a difference between the average GSVs for scans with and without the weight on the lid. Similarly, **Fig. 4** shows a difference between the GSV standard deviation for the weighted and unweighted samples. (The GSV standard deviation is expressed as a percentage of 256 GSV, the total possible range of GSVs.)

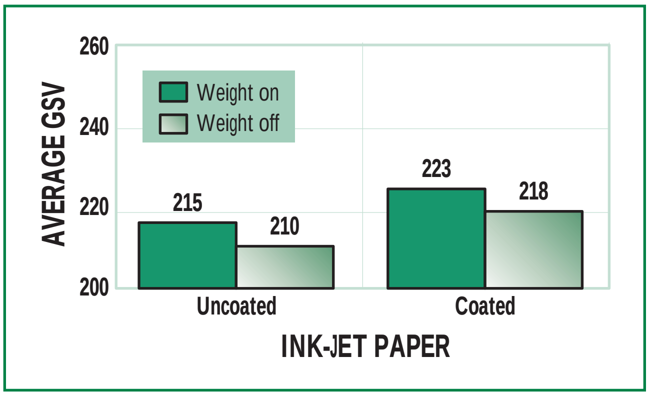
Conclusion: The weight on the lid plays an important role in the measurement uniformity, possibly by causing the sheet to lay flat against the scanner glass, thus overcoming the local sheet thickness and flatness variations.

Measuring a pattern

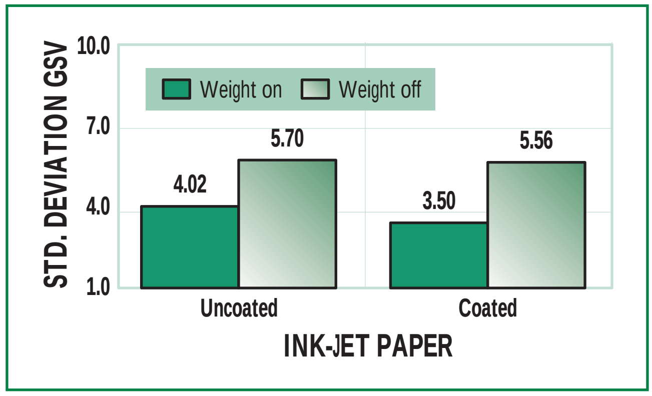
A sheet of sized, uncoated, premium ink-jet paper was printed with the pattern shown in **Fig. 5**. This pattern occupies a space 152 mm × 152 mm in the upper left corner, contains only solid black bars, and has a blank section in its center. The blank area is where the dirt counter can instruct the scanner to sample the background on a preliminary scan without including the pattern.

The bars were chosen after much experimentation with dots and bars of various sizes. It became apparent that the wicking properties, as well as the ink holdout, could be measured if (a) the pattern were not intricate and (b) its perimeter, which is sensitive to wicking, and its center, which is sensitive to holdout, were in balance. To create the bars, the Arial font 120-point capital "I" (vertical bars) and the underline character (horizontal bars) worked well.

The text bars were dimensioned so that they could be sorted by their areas to measure the machine-direction



3. Average GSV for uncoated and coated ink-jet papers with weight on and off (unprinted sheet)

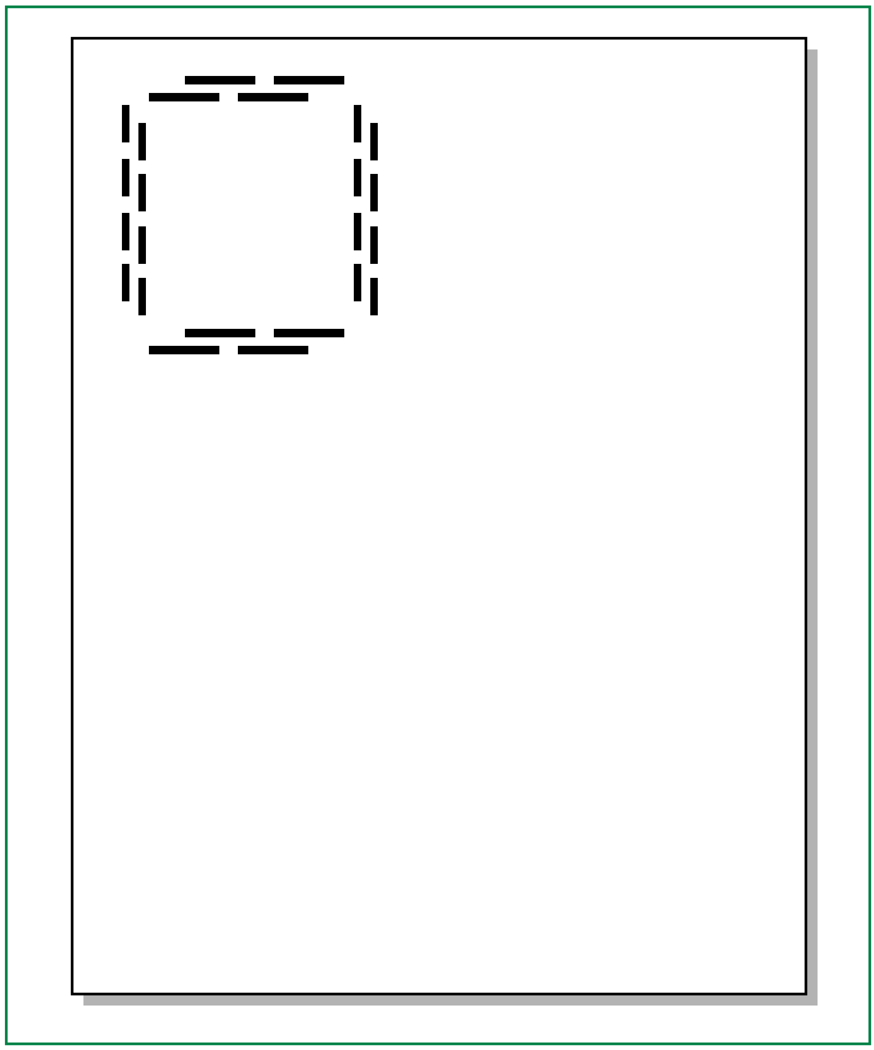


4. Standard deviation of GSV (as a percent of 256-GSV range) for uncoated and coated ink-jet papers with weight on and off (unprinted sheets)

wicking separately from that in the cross-machine direction, if required. It is important the bars be printed as text, since the printer will print "black only" (no colored ink) under text as long as there are no graphics present in the pattern.

In this case, since there was a printed image to measure, the results of the variation in pixel count and the standard deviation of the pixel GSVs below a threshold were reported. **Figures 6 and 7** report standard deviations of pixel GSV and pixel count, respectively. The data in these figures are based on the results of 15 separate scans of two different sheets (coated and uncoated) with and without a weighted lid.

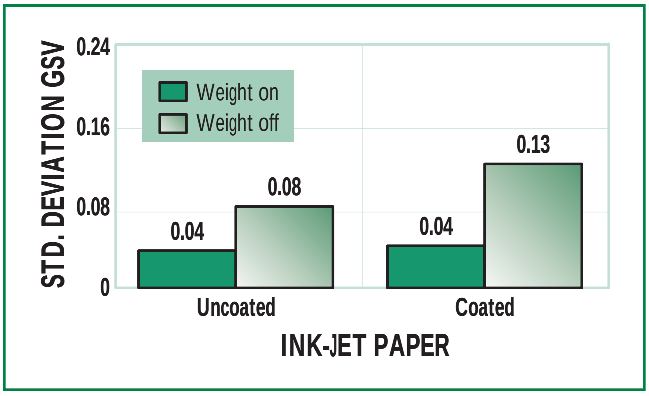
For each scan, the threshold was automatically set by the software to be 80% of a prescan average of the sheet reflectivity, an elected software option. The resulting threshold setting for the unweighted sheets was, on average, 5 GSV lower than for the weighted sheet tests. As a result, the pixel counts and average GSVs were not comparable. Figure 6 shows that the degree of variation of GSV is significantly reduced by adding the weight to the scanner lid. The data in Fig. 7 demonstrate that the weight also affects the variation in the pixel count.



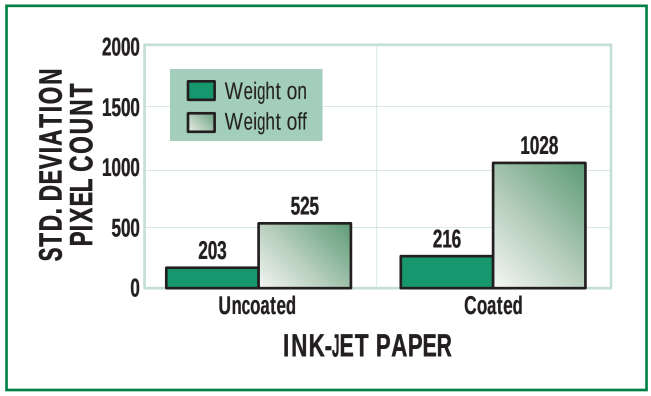
5. Pattern of all-black text bars printed in the upper left 150- mm square on an 8.5-in. × 11-in. sheet

Interpretation: It is speculated that the pressure of the weight flattens the sheet against the glass so the light from the scanner bulb, which is at an angle incident to the glass, does not cast a shadow from the slight cockle caused by the wet ink being absorbed into the sheet.

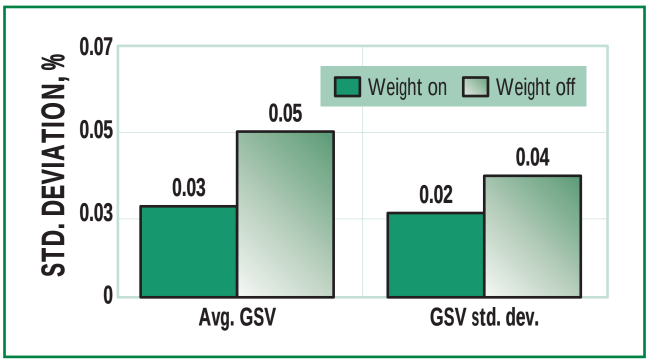
Conclusion: The use of a weight to uniformly flatten the specimen against the scanner glass is necessary to minimize variation in the measurement of image size, a function of pixel count below a nominal GSV value.



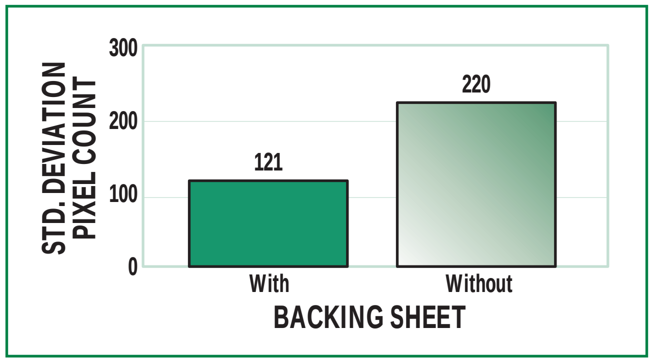
6. Standard deviation of GSV (as a percent of 256-GSV range) for uncoated and coated ink-jet papers with weight on and off (sheets printed with text pattern in Fig. 5)



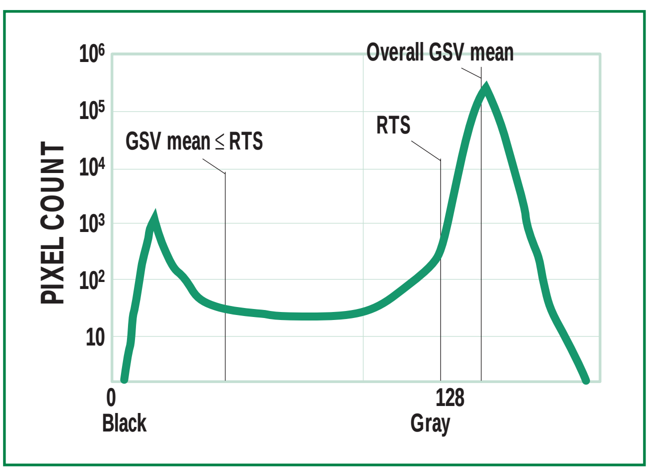
7. Standard deviation of pixel count for uncoated and coated ink-jet papers with weight on and off (sheets printed with text pattern in Fig. 5)



8. Standard deviations of (left) the average GSV of each scan and (right) the recorded standard deviations from the average GSV of each scan (both expressed as a percent of 256-GSV range) for uncoated ink-jet paper with and without a backing sheet (sheet printed with text pattern in Fig. 5)



9. Standard deviation of pixel count for uncoated ink-jet paper with and without second sheet (sheet printed with text pattern in Fig. 5)



10. Typical pixel GSV frequency distribution for a sheet printed with the text pattern shown in Fig. 5

Doubling the sheet thickness

Many users of scanner-based dirt counters have recognized that handsheet opacity affects the dirt measurement. When testing papers from the same grade category, even from the same run, variations in hand sheet opacity can change the apparent brightness of the sheet because the reflective surface of the scanner lid shows through. This effect can lighten the edge pixels on the dirt image and cause a variation in speck size measurement.

Scans with and without a backup sheet of the same grade were made to determine the effect of sheet opacity on the measurement. A sheet of uncoated premium ink-jet paper was printed with the pattern shown in Fig. 5 and aged 24 hours before testing. The same 3.78-kg weight was used on the scanner lid.

The dirt counter was set to scan the sheet 15 times. To expose the measurement to the greatest opportunity for variation, each scan was preceded by an automatic prescan to set the threshold at 85% of the average background GSV measurement.

Figure 8 shows the effect of a backing sheet on the average GSV standard deviation and on the standard deviation of the pixel GSVs below (darker than) a fixed GSV threshold. Here, the term "standard deviation" is used in two different contexts: First as a measure of the pattern

	Pixel count (PC)	Average GSV ($GSV_{Avg.}$)	Std. dev. GSV ($GSV_{Avg.SD}$)	Print quality index (PQI)[b]
Test 1 (control): pixels ≤ average RTS				
	363,245	38.21	51.70	68.48
	366,344	39.35	52.83	86.35
	365,634	39.67	52.75	82.47
	369,364	40.74	53.63	103.85
Average	**366,147**	**39.49**	**52.73**	**85.29**
Test 2 (specimen): pixels ≤ average RTS				
	371,089	41.45	53.48	112.78
	376,330	43.30	54.30	142.97
	373,174	43.76	52.80	122.36
	374,904	43.17	54.81	136.51
Average	**373,874**	**42.92**	**53.85**	**128.65**

[a] The control and specimen sheets were alternately printed and scanned
[b] PQI = (PC – 350,000) × $GSV_{Avg.SD}$/10,000

II. Results of comparative print tests [a]

raggedness (the degree of variation in recorded pixel GSVs) and, second, as a measure of the variation among those same recorded standard deviations that were used to measure pattern raggedness. Also, in Fig. 8 the standard deviation is expressed as a percentage of 256 GSV, the total possible range of GSVs.

Figure 9 shows the actual standard deviation of the pixel count below the threshold. The pixel count will be about 356,000 for the pattern shown in Fig. 5. All of the variations in Figs. 8 and 9 are the cumulative effect of adding the weight to the scanner lid and doubling the thickness of the specimen.

Conclusion: Sheet opacity does play a role in the measurement when the scanner backplate is a high-reflectance gloss white. In the interests of good control and to address the effects of a cumulative error, a uniform reflective white matte surface behind the specimen would mitigate these effects.

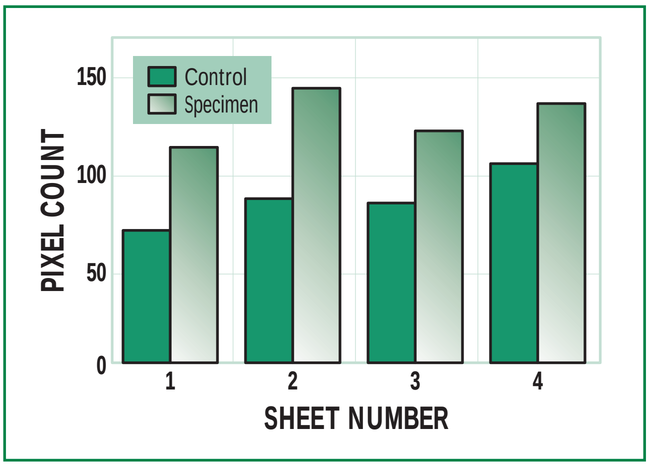
A QUALITY CONTROL TEST

Various grades of commercially available coated and uncoated ink-jet quality papers were tested using the pattern shown in Fig. 5. The results guided the structure of a two-part procedure for field evaluation.

The first part measures the average gray-scale reflectance value of the control sheet. Two test sheets are stacked on the scanner glass felt side down; the lid is closed; and a 3.78-kg weight is placed on the scanner lid. The upper left corner of the sheet (100 mm × 100 mm) is scanned, and the average GSV and standard deviation of the GSV are recorded. These values are then used to calculate the recommended threshold setting (RTS) as in Eq. 1. It has been observed that when the sheet is uniform, the standard deviation is less than 4 GSVs, and a simple multiple of nine standard deviations from the average GSV places the RTS at the root of the pixel GSV frequency-distribution cusp, as shown in **Fig. 10**.

Pixel count	Average GSV ($GSV_{Avg.}$)	Average std. dev. GSV ($GSV_{Avg.SD}$)
Test 1: Overall GSV pixel analysis		
3,717,180	221.69	3.28
3,717,180	222.09	3.33
3,717,180	222.28	3.32
3,717,180	222.58	3.33
3,717,180	222.35	3.33
3,717,180	222.34	3.31
Average	**222.22**	**3.32**
RTS = $GSV_{Avg.}$ – (9 × $GSV_{Avg.SD}$) = 192 GSV		
Optional Test 2: Overall GSV pixel analysis		
3,717,180	222.35	3.27
3,717,180	222.17	3.28
3,717,180	222.47	3.29
3,717,180	222.42	3.28
3,717,180	222.35	3.29
3,717,180	222.58	3.27
Average	**222.39**	**3.28**
RTS = $GSV_{Avg.}$ – (9 × $GSV_{Avg.SD}$) = 193 GSV		
Two-test average RTS = 193		

III. RTS obtained using Eq. 1 and the results from the scan of the unprinted sheet



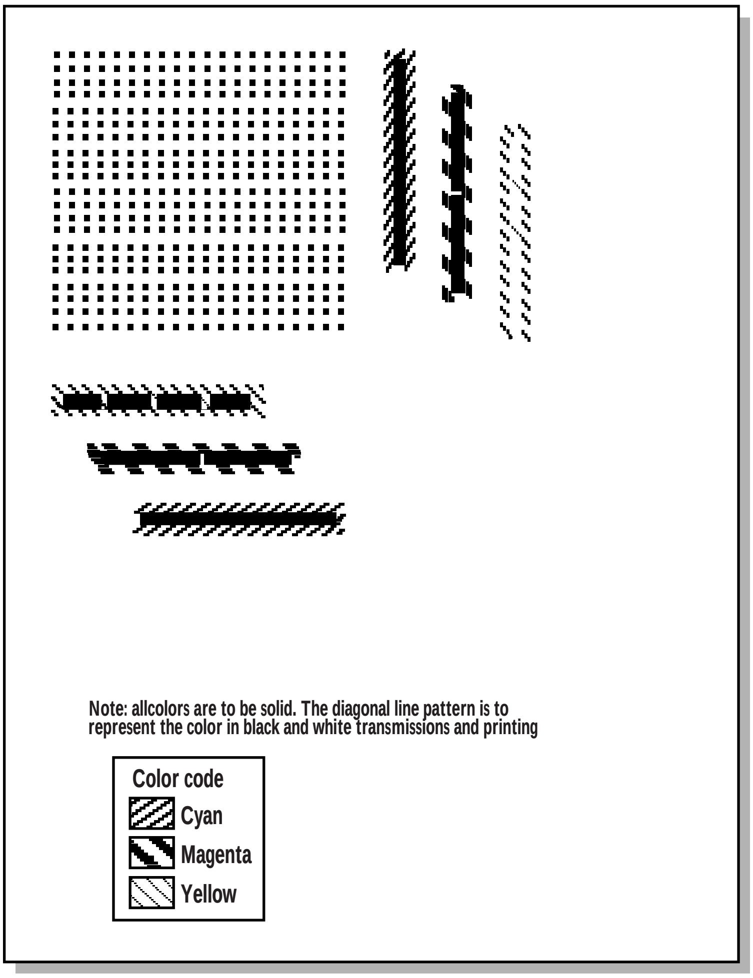
11. Sheet-by-sheet comparison of PQI

$$RTS = GSV_{Avg.} - (9 \times GSV_{Avg.\,SD}) \qquad (1)$$

where

$GSV_{Avg.}$ = average pixel GSV
$GSV_{Avg.\,SD}$ = average pixel GSV standard deviation

If the sheet is not uniform (poor formation), the standard deviation will be greater than four, in which case the RTS is calculated using Eq. 2.



12. Pattern containing a mixture of small text square dots and large graphic bars contained within colored fields

$$RTS = 0.85 \times GSV_{Avg.} \qquad (2)$$

Since the work described here was accomplished on high-quality paper, the RTS was calculated using Eq. 1.

The second part of the procedure is to scan printed control and specimen sheets using the RTS as calculated by Eq. 1.

As mentioned earlier, the work leading to this point had calculated the specific size of printed features such as dots. A different approach was taken in this series. It was reasoned that the computer instructs the printer to lay down a specific number of pixels each time the same pattern is printed. This assumes the computer is without error and the printer works perfectly each time. If this is so, then a variation in the pixel count with GSVs less than the same threshold on two different sheets printed at the same time is probably due to a variation in the performance of the paper. The converse may also be true, i.e., if the paper is held constant and the printer is changed, then the same variations become a measure of printer and ink performance.

It was also decided to use a pattern that concentrated substantially more ink in the center of the printed feature than in its perimeter. This is desirable for assessing the uniformity of holdout or local mottle. It was thought that these properties could be measured as a function of the average pixel GSV and the GSV standard deviation for pixels below the RTS GSV.

The standard deviation of the pixel GSV distribution below the RTS also describes the way the ink has been absorbed into the sheet. Given that a fixed quantity of black ink spreads and is wicking along fibers, then the range of GSVs in the image should indicate the degree of wicking as more light-gray pixels are produced.

Proposed measured variables

When the paper wicks, several variations should occur in the frequency distribution of pixel GSVs below the RTS:

1. The pixel count should rise because the pattern has spread.
2. The standard deviation should also rise because the ink is turning lighter gray as it follows the fibers in the paper and creates a ragged pattern perimeter with more light-gray pixels.
3. The average will probably rise but possibly to a lesser extent because the pattern is dominated by center pixels having less opportunity to wick and turn light gray.

This logic was applied and the relationships were measured through a series of repeatability tests. The results were captured in Eq. 3 as a print quality index (PQI).

$$PQI = (PC - EPC) \times GSV_{Avg. SD}/10{,}000 \qquad (3)$$

where

PC = pixel count below the threshold
EPC = estimated expected pixel count

The EPC was determined empirically by printing the test pattern on a wide variety of papers, scanning them,

Setting	Plain	Premium	Glossy	Transparency
	PAPER TYPE			
Normal	Yes	Yes	No	No
Best	Yes	Yes	No	No

IV. Is there a "primer coat" under the black ink when using combination of graphics and text?

Setting	Plain	Premium	Glossy	Transparency
	PAPER TYPE			
Normal	No	No	No	No
Best	No	No	No	No

V. Is there a "primer coat" under the black ink when no color or graphic is present?

finding the lowest pixel count among them, rounding the count down, and subtracting a small margin. It was reasoned that the actual EPC was less important than the number being constant for all tests evaluated comparatively. If the EPC is too high, the PQI can turn negative as the quality shifts, which is not a problem. **Table II** illustrates the application of Eq. 3.

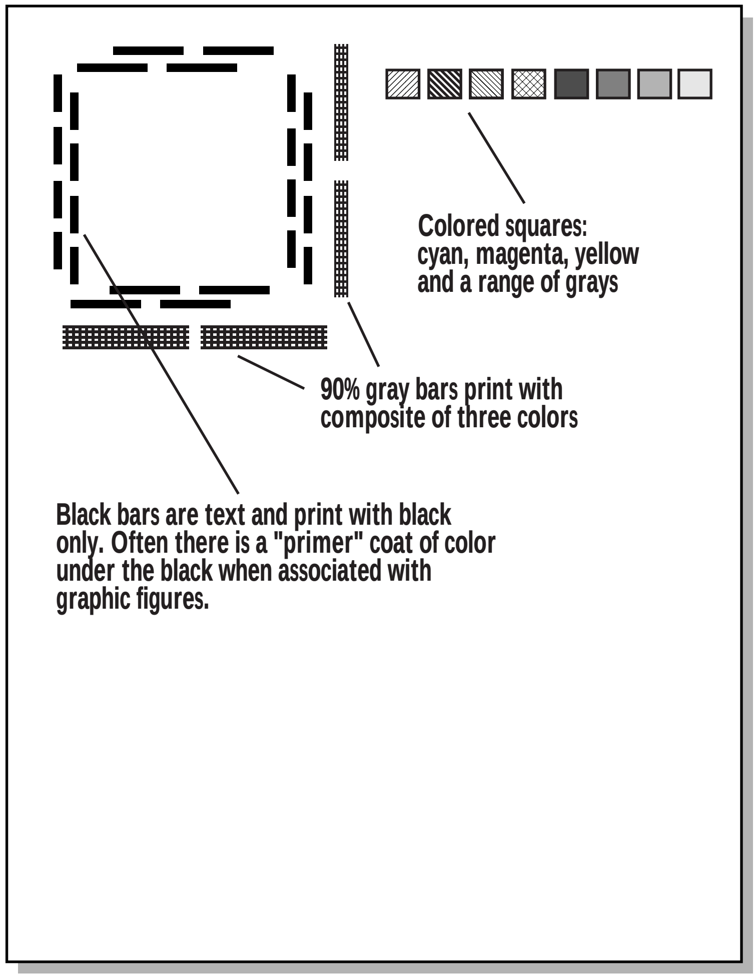
The EPC is arrived at using a single printer. It is quite possible it will be different among printers.

Testing the concept

Samples from two different runs of the same grade of ink-jet paper were received from a mill. These samples were known to have differences measured by other techniques, the results of which were not disclosed to the author.

Step 1. One of the runs was selected as the control. Two unprinted sheets directly from the ream were stacked on the scanner felt side down, the weight placed on the lid, and after a 10-min bulb-warming period, they were scanned six times in rapid succession. The scanner was allowed to cool for an hour and the same test was run again.

The results of these tests and the calculation of the RTS (Eq. 1) using the average of the two groups of six scans are shown in **Table III**.



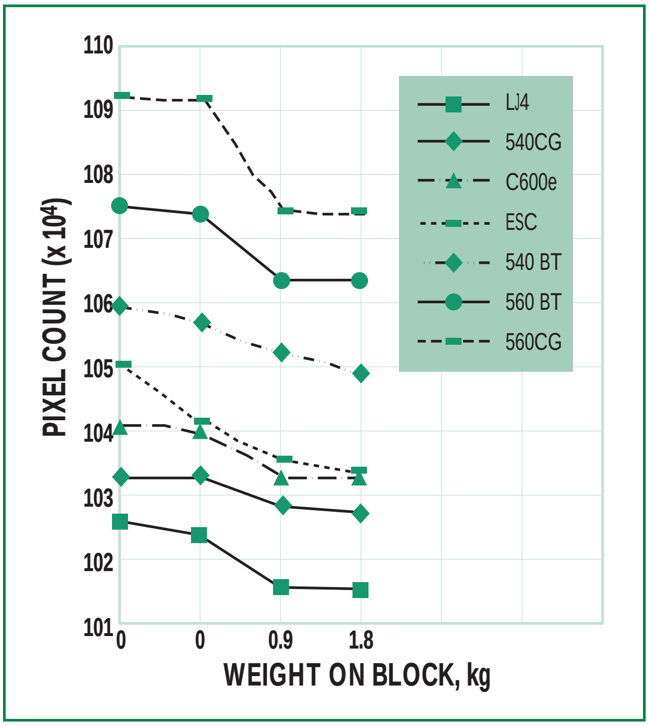
13. Pattern containing colored graphic squares alongside the previous all-text pattern along with bars depicting various shades of gray ranging from 100% to 10% black

Step 2. Four sheets were selected from each run, the control and specimen, and interleaved and printed alternately with the Fig. 5 pattern. The sheets were immediately removed from the printer to dry separately for more than an hour before testing. The scanner was off for more than five hours prior to the test and was warmed for 10 min immediately prior to the test. The sheets were scanned in the order they were printed. After the test, the data were sorted into control and specimen results, as shown in Table II. The results of this test were confirmed by the source of the samples to be similar to their own evaluation.

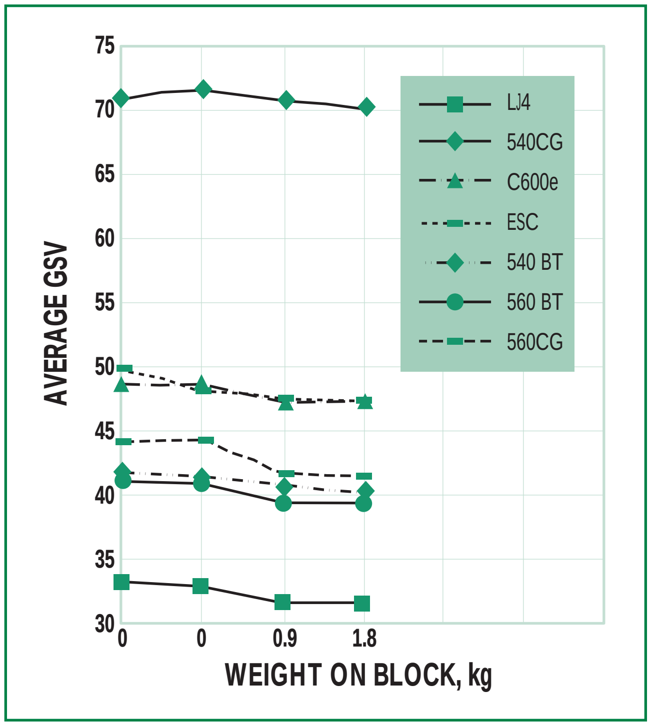
Conclusions: The tests demonstrated the viability of the procedure and the apparatus used. It is interesting to note that extracting any set of two sheets—one control and one specimen—from the sample set would have provided the same comparative result, as seen in **Fig. 11**.

PATTERN AND THE PRINTER SOFTWARE

The commercially available printer used in these tests comes with software drivers that perform an interpretive function. These drivers allow the user to change the way the printer deposits the ink on the paper to fit the type of paper used. Prior to printing, the driver inspects the



14. Pixel count in scanned images (pixels below threshold of 190 GSV) with different weights applied to backing block over printed area. Images were obtained with various ink-jet printer models and printer-driver settings. (No weight was added to the block for the first two trials made on two successive days.)



15. Average GSV in scanned images (pixels below threshold of 190 GSV) with different weights applied to backing block over printed area. Images were obtained with various ink-jet printer models and printer-driver settings. (No weight was added to the block for the first two trials made on two successive days.)

image being sent to the printer for content to determine if it is graphic or text. It then matches the image to the type of paper defined by the user: Is it plain, premium, glossy, or a transparency? Each condition is treated as a separate case, and compensations are made in the quantity of ink deposited, combinations of colored inks, the order of ink application, and the ink-jet deposit pattern.

Some preliminary experimentation with the printer indicated that the driver settings have the greatest effect on the deposition of black ink. To determine the printing effects achieved by the various driver settings, an empty black cartridge was placed in the printer and the pattern used in the main paper (**Fig. 12**) was printed using the full range of paper options. This pattern was chosen because it contains a combination of text and graphic patterns: the dots are text and the bars are graphics. Only two printer modes were tested—"normal" and "best"—and all were in "automatic."

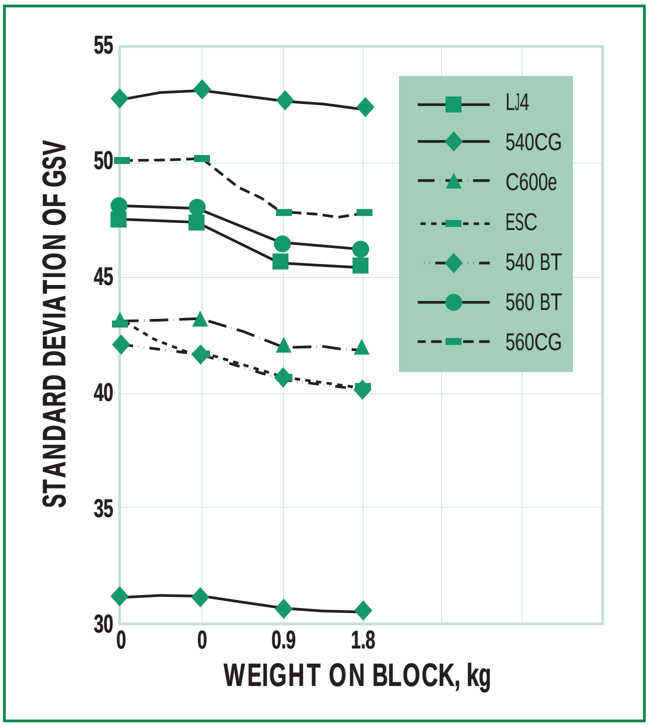
The effect is interesting. When using the plain-paper and premium-paper settings with no black cartridge, the printer lays down what appears to be a "primer coat" of colored ink under the area where the black ink would have been surrounded by color. No text is printed at all unless it is close to a graphic feature, and then it is printed in a light cyan. In the transparency mode, however, no "primer" coat is laid down under the black, and no text is printed.

Table IV shows the combinations where this primer coat is printed under the black ink. The effects of this primer coat are measurable using the image-analysis techniques described in the following sections.

Printing text alone. The text bar pattern in Fig. 5 (capital "I" and underlines) was then tested under the same conditions, i.e., an empty black cartridge with a full color cartridge. As shown in **Table V**, this approach worked. With an empty black cartridge, the printer produced no image at all using the pattern in Fig. 5 under the same conditions used in Table IV.

Adding color to the text pattern. A pattern containing color—based on a variation of the pattern in Fig. 5—was tried next. **Figure 13** shows the colored pattern. **Table VI** shows the results of printing the Fig. 13 pattern. It seems that in the plain and premium settings, the software recognizes the color in the pattern and then lays down the color primer coat under the horizontal bars even if they are a form of text. The vertical bars were unaffected and did not print under any conditions. Note that the "glossy paper" setting printed a composite gray horizontal bar but no vertical bar.

Printer setting recommendations. The printer setting should be uniform. All comparative tests should be made using the same setting, the same software, and the same printer.



16. Standard distribution of GSV frequency distribution (pixels below threshold of 190 GSV) with different weights applied to backing block over printed area. Images were obtained with various ink-jet printer models and printer-driver settings. (No weight was added to the block for the first two trials made on two successive days.)

Setting	PAPER TYPE Plain	Premium	Glossy	Transparency
Vertical text bars (capital "I")				
Normal	None	None	None	None
Best	None	None	None	None
Horizontal text bars ("underline" character)				
Normal	Blue primer	Blue primer	Composite black	None
Best	Blue primer	Blue primer	Composite black	None

VI. Printer behavior for text elements in the pattern in Fig. 13 when printing with an empty black-ink cartridge

Code	Model	Setting
LJ4	Hewlett Packard Laser Jet 4P	Normal
ESC	Epson Stylus Color	Normal
C600e	Canon BJC 600e	Normal
540BT	Hewlett Packard 540	Black text
540CG	Hewlett Packard 540	Color graphics
560BT	Hewlett Packard 560	Black text
560CG	Hewlett Packard 560	Color graphics

VII. Codes for printer models and settings in Figs. 14–16

Conclusions: For this printer and this generation driver software, the "transparency" settings of either "normal" or "best" seem to provide the most predictable results. Whether there is color present or not, 100% text black is not printed as a composite of colors and is printed without a primer. The 90% gray areas are printed as a composite.

OPTIMIZING THE WEIGHT AND THE REFLECTIVE SURFACE

The initial tests showed that placing sheets of the same grade behind the specimen and placing a weight on the scanner lid improved the ability of the scanner to reproduce its measurements. The next step was to refine the manner of applying weight. Inspection of the scanner lid revealed that although it had high reflectivity and was uniformly white, it had an uneven surface. It was conjectured that the weight on the lid used in the previous tests caused the uneven lid surface to conform to the glass and compress the specimen sheet more evenly.

Based on this assumption, and the fact that the 3.78-kg weight was distributed across the entire scanner lid, pressure per unit area was calculated and used to determine that approximately 1.1 kg was on the 150 mm × 150 mm area measured in the test.

A block was made of seasoned oak measuring 150 mm × 150 mm and 19 mm thick with a weight of 0.3 kg. It was faced with two layers of white felt and was tested with weights of 0.9 kg (2 lb) and 1.8 kg (4 lb) placed on top of the block. The block was also tested with no additional weight.

A series of test scans with the felt-faced block behind a printed sheet proved that weight alone was not the answer, at least not with the felt facing. Previous work had demonstrated a 24-lb sheet with exceptionally good formation, highly filled, calendered, and very bright (232 $GSV_{Avg.}$). Two sheets of this paper were carefully cut and folded to form a surface for the white-felt face of the oak block. A uniform smooth bright white surface with a cushioned yield was formed.

This white-paper-faced block was placed on the printed paper specimens immediately behind the printed area to force the specimen against the scanner glass. Different weights were placed on the block, and pixel counts, average GSV, and standard deviation of GSV were calculated and plotted in **Figs. 14–16**, respectively, for various ink-jet printer models and driver settings.

A series of printouts using the pattern described in Fig. 5 was provided by a mill. The image was printed on 20-lb reproduction-grade paper using the various printers, printer settings, and codes listed in **Table VII**. No extra unprinted sheets were provided, so a fixed threshold of 190 was used on all tests, and the RTS was not calculated. Each of the printed sheets was scanned three times, and the pixel count shown in Fig. 14 is the sum of the three scans. The average GSV in Fig. 15 and the GSV standard deviation in Fig. 16 are the average of all three scans.

The pixel count should be an indication of the relative amount of wicking. It was expected that the laser printer would produce the lowest readings, which it did. These tests were spaced out over a 36-hour period and were run in batches determined by the weight used.

It was not until the second run of zero weight on the block that it was learned that the block had to be placed so it did not touch the edge of the metal frame surrounding the glass. The first test of zero weight on the Epson printer may have been compromised in this way. It seems the slightest relief of pressure influences the test. The heavier weights overcame this effect. Care was taken to properly place the sample and block, and a simple guard was constructed to cause the block to stand off from the frame.

Little attention had been paid to the blackness (average GSV) of the printed image in the previous tests. This time, the different printer settings produced a range of black from that of the laser printer to the composite gray of the ink-jet color printers. As shown in Fig. 15, the test uniformly measured these differences and followed the same pattern of change in blackness (lower GSV) with increased weight. The change was less dramatic but consistent.

The important difference is in the absolute average GSV comparison of one printer with another. Comparing the pixel count data and the average GSV data, it would appear that the Epson and the Canon printers are approximately the same. Visual inspection recognized the differences in print quality immediately. The laser printer obviously produced the blackest image consistently.

The standard deviation for all the pixels in the image indicates the degree of uniformity in the reflective value for all the pixels less than 190 GSV. The GSV is limited to 256 values, so the standard deviation is an excellent measure of relative variation. As shown in Fig. 16, this series of tests points out the necessity of controlling the print method very carefully. It was expected that the laser print would have the least variation, but it turns out that the most uniform pixel gray-scale values were with the composite black from the 540 using the color graphics setting. Unfortunately, as shown in Fig. 15, this same sample produced a very light gray image.

Conclusion: A block weighing at least 1 kg, faced with a flat-cushioned, high-brightness, uniform white matte surface 150 mm × 150 mm should be used to hold down the specimen. The block should be placed over the printed area on the specimen. The printed pattern should be no larger than the block face and the area scanned by the image analyzer. Since the method is not pattern or location specific, the block can be fabricated to cover any area appropriate to the scanner and printed pattern location as long as it is faced properly and weighted proportionally.

SUMMARY

There is one salient observation from all these tests. There are a lot of variables in the evaluation of ink-jet print quality when using commercially available equipment. The advantages of developing a good method using these tools, however, are manifold: the greatest being simplicity, speed, low cost, and the fact that the end user of the paper will probably be using similar equipment.

The variables identified are:

- Printer: dual or single cartridge
- Printer-driver software settings
- Print pattern interaction with driver software
- Printer performance over time
- Wet-ink-induced cockle in the sheet
- Scanner warm-up time
- Weight distribution on the specimen
- Smoothness of the weighted backing surface
- Reflectivity and uniformity of the weighted backing surface
- Number of scans in measurement base data
- Scanner performance over time.

Each of these variables can be controlled by:

1. Establishing the printer make and model and learning which driver setting provides text black without a colored "primer" and prints a composite color 90% black. Use the same settings in each established test procedure.
2. Interleaving "control" and "specimen" sheets when printing and scanning to overcome sheet-to-sheet performance variations in both devices.
3. Setting image-analysis software so the scanner timer keeps the bulb on all the time or has a 5–10-min warmup prior to scanning, which will level the scanner performance.
4. Placing a uniform weight on the sample to smooth the cockle and overcome the minute shadows from the low-incident-angle scanner bulb.
5. Using a uniformly white matte reflective surface behind the sample to overcome backscatter variations caused by variations in formation and basis weight.
6. Using at least three scans in a group measurement of a single printed sheet or three separate sheets scanned individually and reported as a single group measurement to overcome variations in both printer and scanner performance.

7. Using image-analysis software that reports the pixel count, average gray-scale value, and the standard deviation of the individual pixel gray-scale values below a variable threshold.
8. Using image-analysis software that automatically sets the measurement threshold based on the calculation of the standard distribution of the frequency distribution of the sheet pixel gray-scale reflectivity. On the white papers tested, placing the threshold nine standard deviations away from the mean GSV is usually just where the fiber stopped its major contribution to the image. By using the automatic threshold setting, the threshold will change in concert with variations in the scanner bulb illumination.
9. Using the black, white, and neutral gray reflective "tiles" provided with the image-analysis software to check the scanner for excessive drift caused by changes in the bulb and the electronics associated with image acquisition. Scanner users are given no control over the size of the pixel (pixel size is fixed) nor over the brightness of the image (image size is set automatically by the scanner electronics). The scanner measurement accuracy and repeatability are, as a result, totally dependent upon the threshold setting relative to sensitivity of the scanner at the time the test is run. Items 2, 3, and 8 address gradual changes normal to the scanner, but the "tiles" will determine if the scanner bulb has moved beyond its ability to measure well. A change in the neutral gray tile reflectivity of 10% is cause for concern and possible bulb replacement.

These steps are easily applied and will result in a fast, simple procedure for evaluating ink-jet print quality. TJ

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