ON-LINE MONITORING OF POSTAGE STAMP COLOR AT THE BUREAU OF ENGRAVING AND PRINTING

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ABSTRACT

This paper presents a user's viewpoint on the contribution that on-line radiometric colorimetric measurements make toward improving color consistency of postage stamps printed at the Bureau of Engraving and Printing (BEP). Color consistency of postage stamps is very critical because postage stamps receive the closest inspection among products produced by web printing processes. Through an intensive developmental program the BEP has effectively adapted large aperture colorimeters to monitor stamp color and appearance on-press, in real-time. In addition to implementing the hardware necessary to make the actual stamp color measurements, this effort also involved the introduction of the L.a.b color measurement scale as a means for describing stamp color variations in terms that directly correspond to the color perception characteristics of the human visual system. As operational experience was gained with on-line color monitoring, the techniques implemented also proved very effective for generating quantitative quality profiles of finished stamp rolls.

*Bureau of Engraving and Printing

DISCUSSION

The consistency of color and appearance are very critical factors to the quality and security of postage stamps. The Bureau of Engraving and Printing (BEP) as well as most commercial printers have much experience with the difficulties of maintaining consistent color/appearance during production runs. This fact is the underlying reason that BEP has historically maintained an active interest in developing and applying techniques that could provide a reliable, quantitative assessment of actual product color/appearance.

The major step in BEP's advance toward quantitative assessment of color and ultimately real-time measurement of color on-press was experimentation with the Hunter L, a, b color scale and "large aperture" tri-stimulus colorimeters. An important milestone was reached when a numerical scale for measuring color/appearance was demonstrated to be applicable to postage stamps. The sole means for determining and communicating color conditions was through visual inspection and verbal descriptions respectively. Examples of common terms used for communicating color conditions are as follows:

Excellent Match	Too Light	Too Red	Needs More Red
Good Match	Too Dark	Too Yellow	Needs More Yellow
Fair Match		etc.	etc.
Unacceptable Match			

Presented in Figure I is an illustration of the Hunter L, a, b Color Scale.

L,a,b COLOR SYSTEM

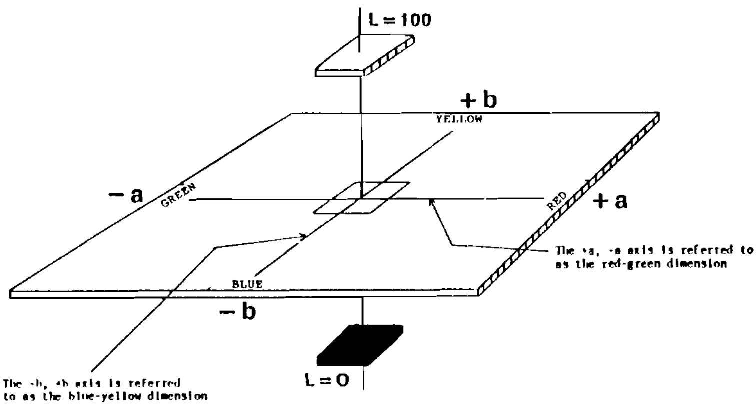


Figure 1

The aforementioned verbal descriptors of color conditions appear simple and self explanatory. However, when applied to stamps, they have to carry significantly more "information" due to characteristics which are inherent to stamp images and their associated printing formats. Foremost among these characteristics is the stamp's small physical size. Stamps are small, highly detailed, printed subjects with complex coloring. When stamps are visually inspected for color and appearance, the verbal descriptors of color listed previously refer primarily to a global field of view consisting of many stamps viewed simultaneously, this situation is quite different from other commercial printing. A further point worth noting is that small physical size makes it difficult to make accurate densitometer measurements for specific colors directly in printed areas where the actual visual inspections are made.

The problem of color measurement had interested BEP for many years and had also been the subject of experimentation and testing with both spectrophotometers and densitometers. These instruments ultimately proved unsuitable due to non-compatibility between instrument optics/sensor head design and stamp image. The spectrophotometer used had a 1" aperture and illuminating sphere geometry while the densitometer had a 0.25" measurement spot size. It was at this point that experimentation with a large aperture colorimeter began.

The large aperture colorimeter has a sensor head design that allows the instrument to effectively integrate/average the light reflected from a group of images and convert the "integrated" light via silicon photodetectors into electrical signals which correspond to tristimulus X, Y, Z color scale values. The X, Y, Z values are further processed by the colorimeter's microprocessor into the familiar L, a, b color scale. Conversion to L, a, b color scale is accomplished using the following formulas developed by R. S. Hunter in 1958.

$$L = 10\ Y^{1/2}$$

$$a = 17.5\ \frac{(1.02X-Y)}{Y^{1/2}}$$

$$b = 7.0\ \frac{(Y-0.847Z)}{Y^{1/2}}$$

Where X, Y, Z are the CIE tristimulus values of the sample/object's color stimuli. Critical to the capability of integrating image color were the fiber optic array in the colorimeter sensor head and the annular mirror assembly for uniform sample illumination. The colorimeter's fiber optic array consists of an assembly of several thousand optical fibers arranged in a randomly oriented configuration (non-coherently bundled, transmitted image is not coherent). This technique integrates the light reflected from the stamp image(s) and transmits the light to four silicon photodetectors equipped with filters that closely match the visual color response of the C. I. E. Standard Observer. While the fiber optic assembly performs the image integration function, the annular mirror assembly insures that illumination directed at 45° is uniform over the entire area being measured. Regarding the "large aperture" designation for the colorimeters used at BEP, an instrument with 2" diameter inspection port was used for static stamp color measurements while an instrument with 5" diameter inspection port was installed on-press for dynamic color measurements at production speeds.

The L, a, b Color Scale is recognized scientifically and commercially as a practical measurement scale for numerically representing the color/appearance characteristics of a wide variety of products. Being able to quantitatively describe an object's color, in numerical terms, provide the basis for the most important use of the L, a, b Scale; the computation of numerical color differences. With numerical color differences it is possible to quantitatively describe the visual color difference that may exist between a production sample and the product "color standard." When printers or QA personnel visually compare a production sample to the "color standard", the accuracy of the inspection is very dependent on the following factors:

a. Ability to "see" different colors.

b. Ability to "see" color differences.

c. Ability to communicate perceived visual color differences.

d. Lighting conditions.

e. Relative positions of observer, product sample, and color standard.

f. Impact of fatigue and/or concern about nearby production machinery on concentration during inspection.

"Visual" color inspections are easily influenced by factors other than the product itself.

BEP's experience and success with real time monitoring of color was based on prior experimentation with static color measurements using laboratory instrumentation. The static colorimeter measurements were made on an instrument system having a 2 inch diameter sample inspection port. The initial results obtained were compatible with data that was to be generated later with the on-line color monitor because the significant design features of both systems, the fiber optic sensor head and annular mirror assembly for sample illumination, were very similar. Although not realized initially the static color measurement work provided an excellent platform for introducing color measurement technology to BEP products, but most importantly, it served to develop an in-house technical group with the following expertise.

* color/appearance measurement scales and their specific application to BEP products

* Operation, calibration, and maintenance of colorimeters and spectrophotometers

Examples of the effectiveness and accuracy of static color measurements and corresponding data are shown in Figures 2, 3, and 4. This data was obtained from stamps printed by the gravure process. The graph in each figure represents data from actual static stamp color measurements. In Figure 2, the point marked "out of Spec" represented color that had deviated beyond the range of acceptability. The printer's description for this color deficiency was that the "sample had lost green." The magnitude of Figure 2's color deviation was very significant.

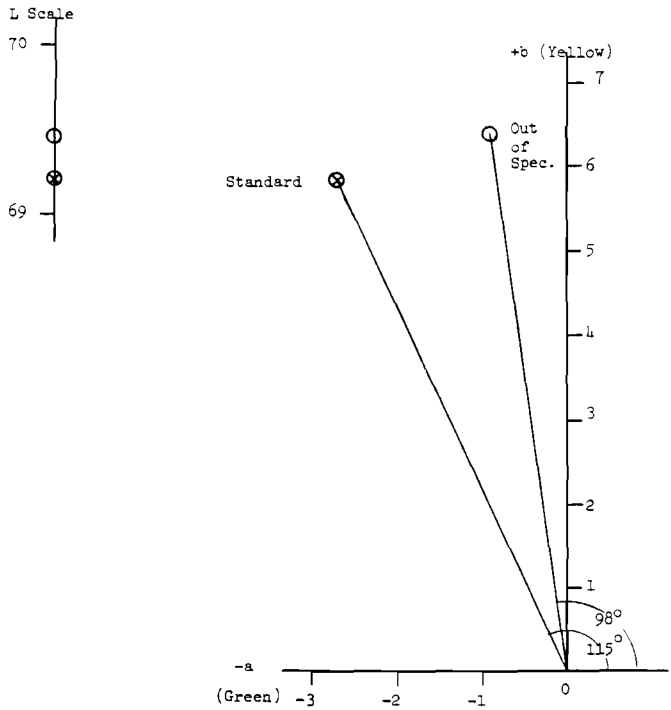

L Scale
70
69
+b (Yellow)
7
6
5
4
3
2
1
Out
of
Spec.
Standard
98°
115°
-a
(Green)
-3
-2
-1
0

Figure 2

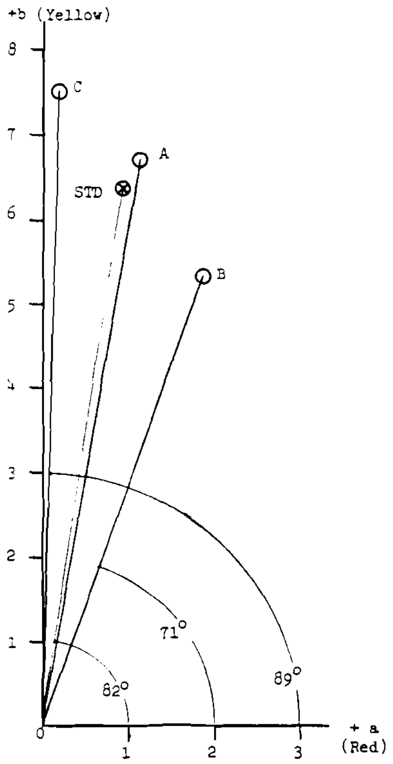


Figure 3

Figure 3 illustrates how color varied over consecutive production days. This data shows that the color match between Sample A and the Standard was very good. Samples B and C however were significantly different from the Standard. Samples B and C also serve to illustrate that customer complaints on product appearance are due to color variations on both sides of the product color standard. In this situation the color match of both, STD to C and STD to B may be borderline unacceptable while the color match between B and C is conspicuously unacceptable. When visually compared Sample C

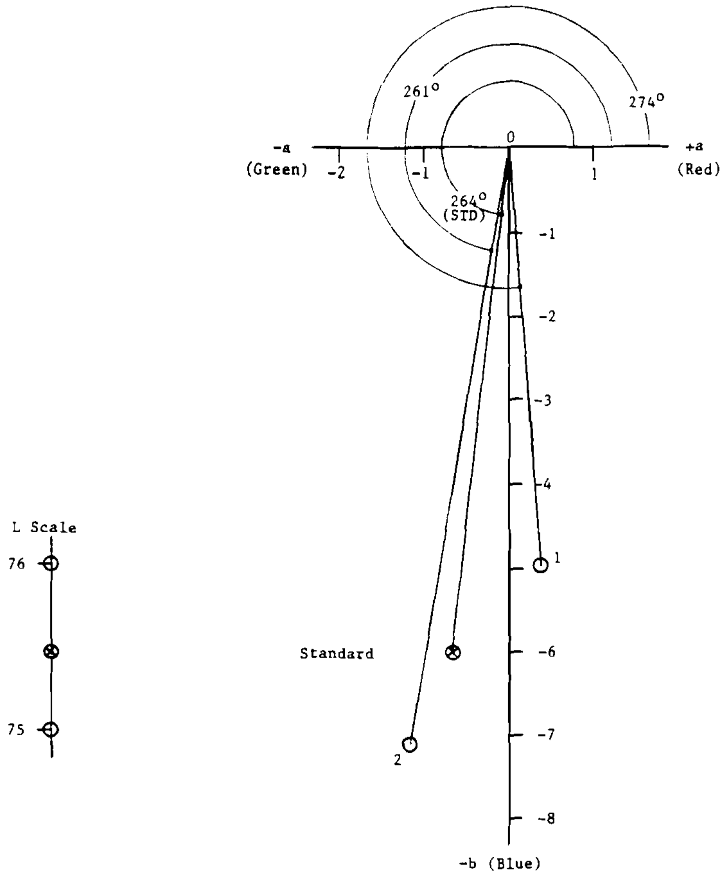


Figure 4

appeared very yellow and Sample B very red. Figure 4, which is an original presentation of color data as provided to printers and foremen, shows a dramatic correlation between visual color inspection results and instrumental data. In this example Samples 1 and 2 were obtained at different periods of production. What is significant is that two different foremen, one inspecting the color match between the Standard and Sample 1 and the other the match between the Standard and Sample 2, both stopped printing to take corrective action because in their opinion they had "lost color." Through examples of correlating color measurements with visual inspection results (as demonstrated in Figures 2, 3, and 4) and conducting visual perception tests with printers, numerical color tolerance guidelines were established. These guidelines are presented in Figure 5.

Description of Color Match as determined through visual inspection (difference between sample and product color standard)	Numerical Equivalent for ΔL, Δa Δb
Excellent Match	Δvalue = 0 to .3
Good Match	Δvalue = .3 to .7
Fair Match	Δvalue = .7 to 1.0
Poor Match	Δvalue = 1.0 to 1.4
Unsatisfactory Match	Δvalue greater than 1.4

for

L, a, b of Production Sample Color − L, a, b of Color Standard = Color Difference or ΔL, Δa, Δb

Figure 5

As stated earlier in this paper, BEP's experimentation with static stamp color measurements was an excellent approach to developing a technical background in color measurement technology. However, applying color measurement technology in the form of static instrumentation is not an effective means for improving color control in a web printing process particularly given the high level of variables and dynamics that effect web processes of any type. To put it simply, static color inspection can not provide the sample frequency needed to monitor (and ultimately control) a printed web with a high degree of confidence. To help visualize this situation, the following characteristics of BEP's gravure printing process are presented.

Length of web in printed roll	-	20,500 ft.
Typical press speed	-	650 ft./min.
Time to print one roll	-	32 min.

Press equipped with automatic splicer
(ie web is not stopped to remove completed roll)

In this production scenario only the end segment of a printed roll is available for performing a static color measurement. The limitation described here for static measurement correspondingly provides the incentive for pursuing techniques that can measure color on a moving web at production speeds.

BEP's entry into monitoring/measuring color on-line was initiated with the installation of a commercial optical sensor on our seven color gravure press. As mentioned previously, this sensor has a 5 inch diameter sample port and the capability to integrate and measure color <u>continuously</u> at rates of 7 samples per second. Continuous color measurement means that neither the illumination source or photodetectors are strobed. Instead, the sensor head "looks at" the web continuously while the system's microprocessor automatically polls the photodetector output voltage. Since the signal/data being read from the colorimeter sensor head is a measure of a continuous web process it requires a more specialized processing than a simple conversion into L, a, b scale values. The color data generated must be presented to printers in a convenient format that provides immediate identification of stamp color's current status relative to the respective <u>color</u>

standard. For BEP's application, the color measurement results are presented in the form of the Color Difference Chart illustrated in Figure 6. This illustration exactly duplicates the face of the chart recorder used in BEP pressrooms. △ L, △ a, and △ b are each plotted in a different color pen, usually green for △ L, red for △ a and blue for △ b. The

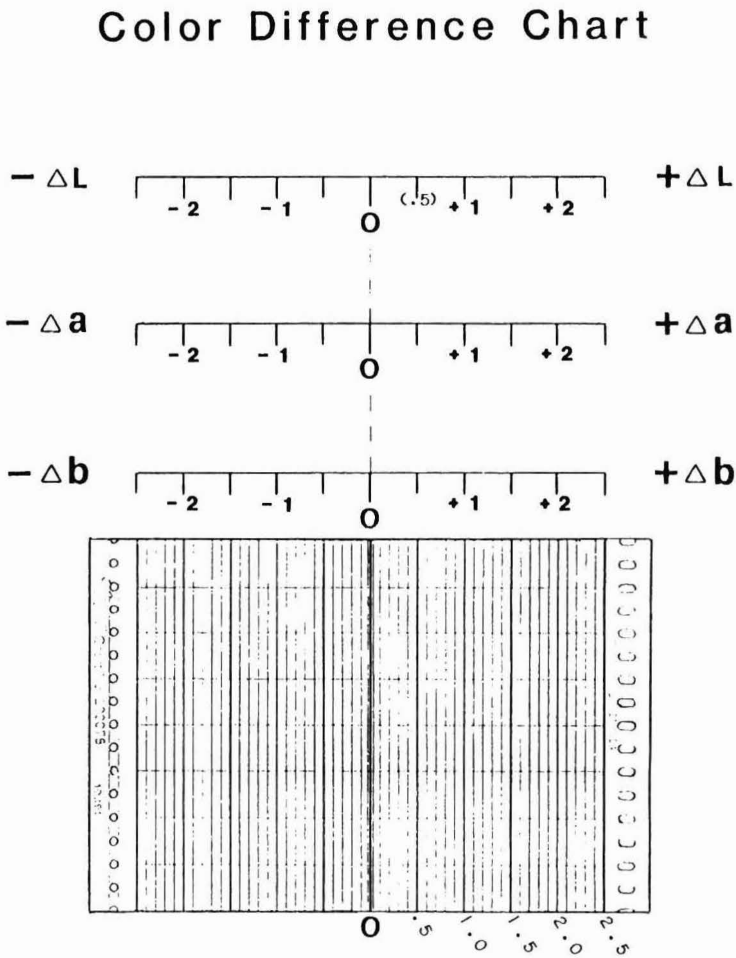


Figure 6

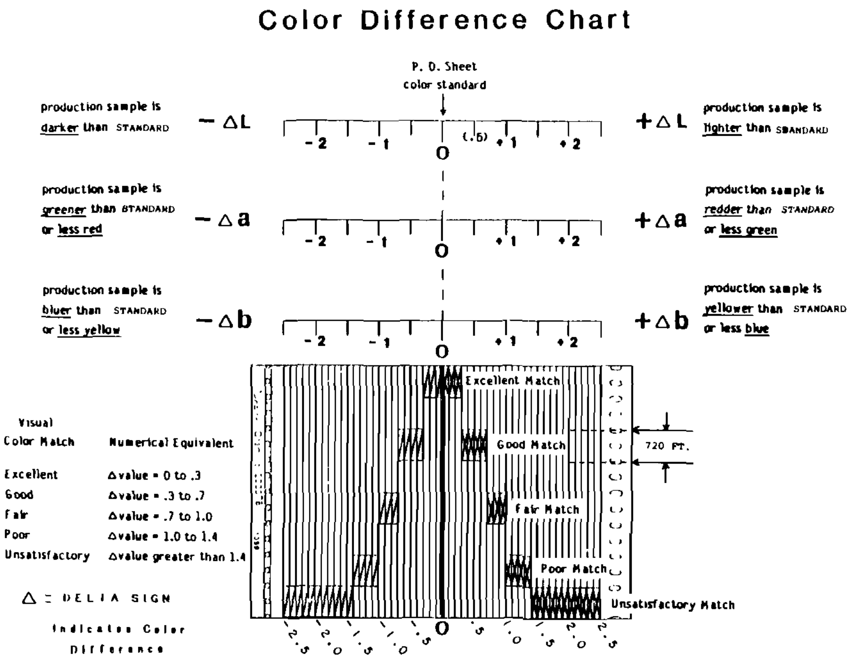
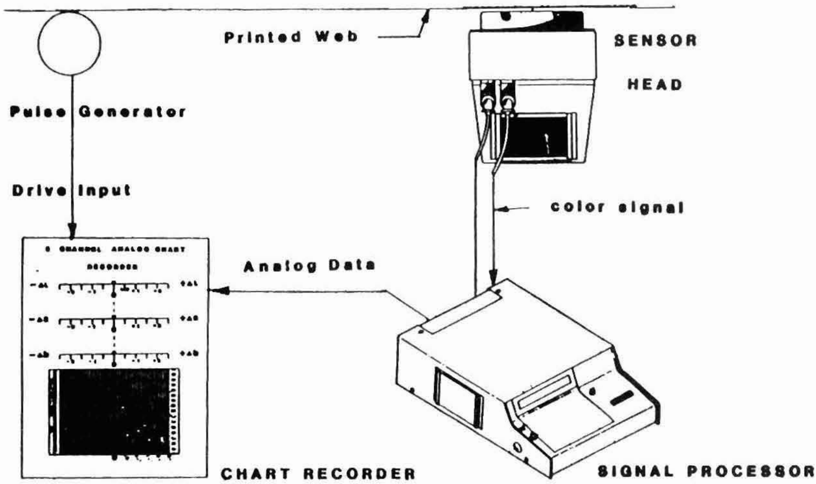


Figure 7

horizontal scale displays the magnitude of actual color difference from the standard and the vertical scale web footage transported past the colorimeter sensor head. The special feature of this data display format is that a very close match to the color standard exists when the three chart recorder pens register O. A Color Difference Chart with full explanation is presented in Figure 7 for clarification. Please note that the color tolerance guidelines presented in Figure 5 are also applicable here. An illustration of the complete on-line color monitoring system is provided in Figure 8.



ON-LINE COLOR MONITOR SYSTEM

Figure 8

Before proceeding to the discussion and presentation of the on-line color measurement results it is appropriate to discuss the color standard since on-line monitoring is in reality a continuous comparison process to a specific standard/reference. When a new stamp first goes to press, an attempt is made to print a "sheet" that closely matches the stamp issue's approved model or proof. To print this sheet printers must effectively combine the capabilities of the press, materials, and printing cylinders or plates with their collective printing experience. The process of working toward the color/appearance standard is very dynamic in that variables such as web speed, registration controls, doctor blades or plate packings, etc. and ink are constantly adjusted to produce the highest quality standard possible. It is during this phase of production that the best opportunity exists for generating L, a, b values for the color standard.

While printers are working toward the standard, the color monitoring system is set up to continuously monitor/measure the printed web and print out corresponding L, a, b values. Please note that L, a, b values are printed out at this time and not $\triangle$ L, $\triangle$ a, $\triangle$ b color differences. When the Foreman signals that a candidate standard has been printed QA personnel will then examine the color monitoring system's printouts to determine which L, a, b values represent the measurement of the standard sheet's color. After this determination is made the L, a, b values for the color standard are then entered for storage in the color monitoring system's "Product Standard Register" where they will be used to compute color differences of incoming web color measurements.

Presented in Figure 9 is a Color Difference Chart from a stamp job printed on BEP's 7-color gravure press. To illustrate the clarity of data presentation and data compression capability of the Color Difference Chart it is worth noting that Figure 9's chart segment represents the complete set of color data for a roll 20,000 feet long. Also shown in Figure 9's chart is an important guideline for printers, the $\pm \triangle$ 0.8 tolerance window. This boundary represents the maximum color variation limit for the majority of multi-color stamps monitored to date. In general, when $\triangle$ L, $\triangle$ a, $\triangle$ b goes outside the tolerance window, it is usually due to one (or a combination) of the factors listed below.

* large change in paper color.
* Change in ink viscosity.
* Print cylinder, or plate, transferring insufficient or excess amount of ink onto paper.
* Doctor blade problems.
* Press out of register.
* Loss of print unit impression pressure.

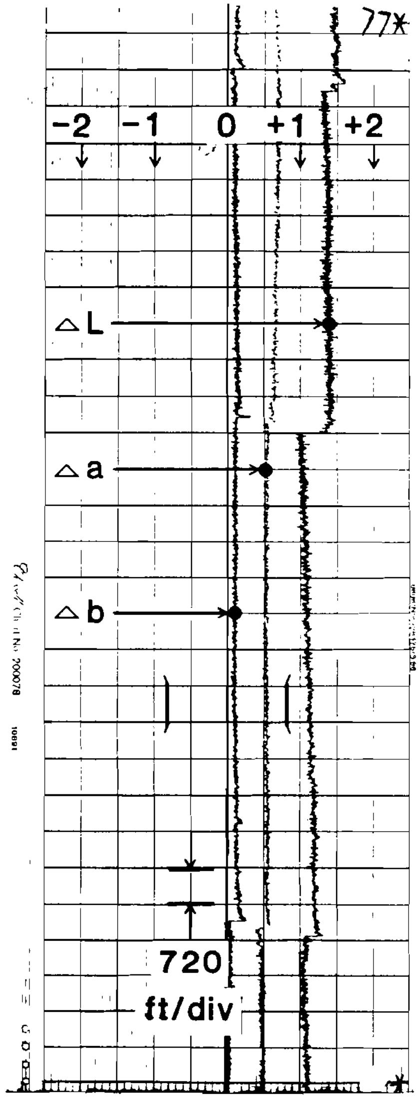


Figure 9

An additional benefit of continuous on-line color monitoring with output data provided on Color Difference Charts is that a permanent record is made of a printed roll's "quality profile." The quality profile is a chart recording that shows, through variations in continuous $\triangle$ L, $\triangle$ a, $\triangle$ b values, major perturbations which occurred while a roll was being printed. This information provided in hard copy form provides a very powerful analytical tool which further increases the on-line color monitor's effectiveness in improving productivity. Specifically, the quality profile indicates 1) the color variations that occurred within the respective roll, 2) the presence of other printing flaws and anomalies, 3) a probability level for a roll containing the highest quality printing, and 4) an estimate of roll yield in terms of lineal footage with acceptable print quality. In Figures 10, 11, 12, and 13 illustrations of quality profiles from 4 stamp rolls (same stamp issue) are presented. An explanation of the aforementioned figures is given in the table below. Each quality profile is representative of a 20,000 ft. roll printed at 650 ft./min.

Figure 10	-- Consistent printing - no major variations indicated
Figure 11	-- Mill splice - change in paper color indicated
Figure 12	-- Press Out-of-Register - causes major change in stamp appearance
Figure 13	-- Staining - caused by worn doctor blade; quality returned to within specification after changing doctor blade.

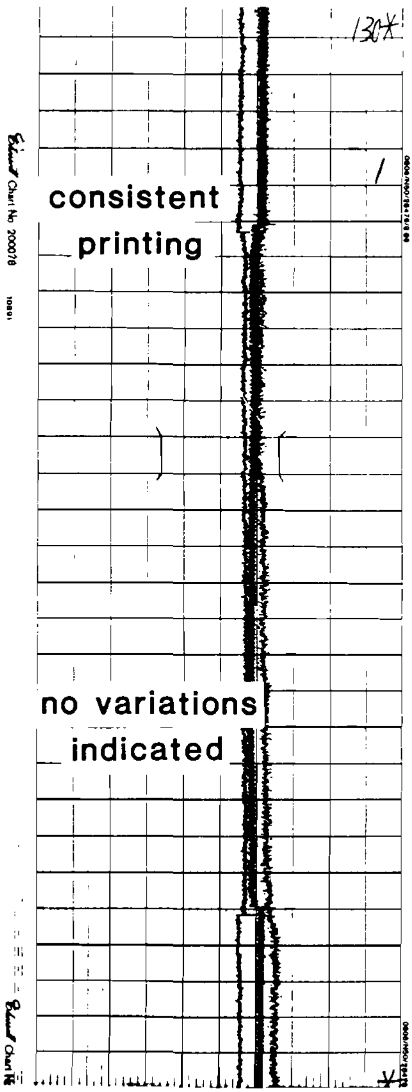


Figure 10

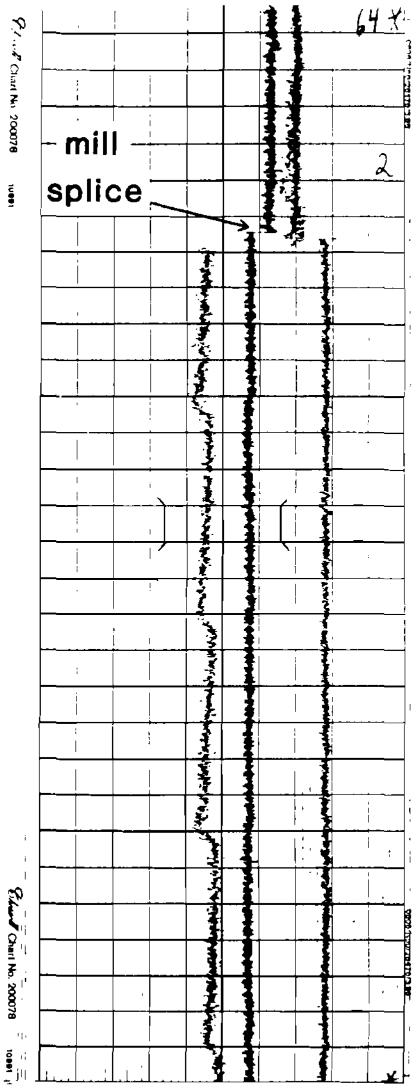


Figure 11

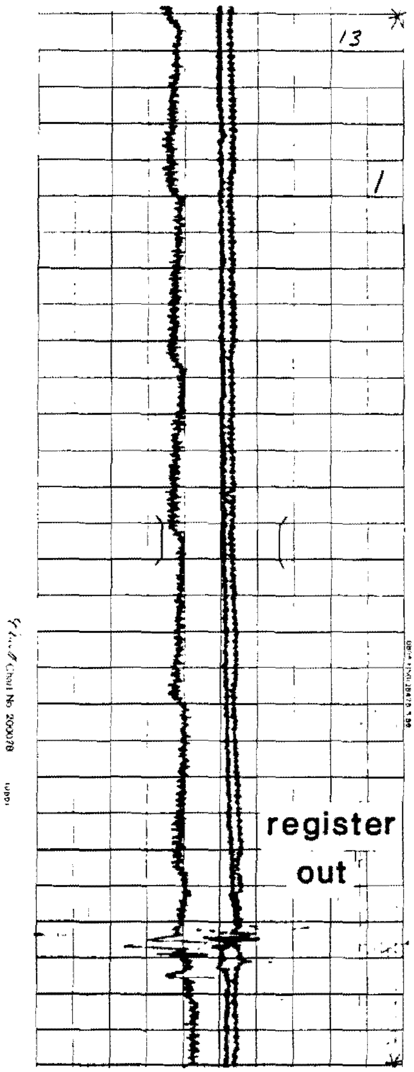


Figure 12

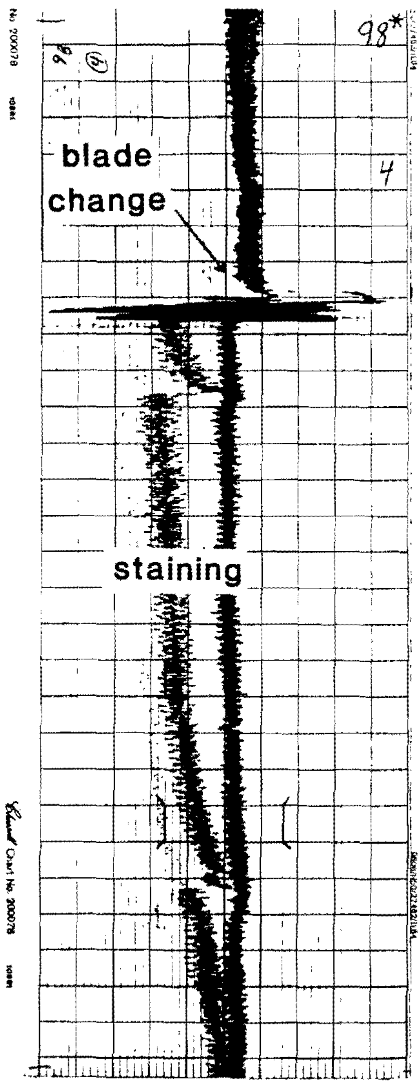


Figure 13

CONCLUSION

The Bureau of Engraving and Printing's experience with colorimetry and its application to measuring postage stamp color resulted in the implementation of process monitoring techniques which improved product quality and aided productivity. Plans are currently underway to develop a specialized on-line color monitor system with performance capabilities that more closely matches our product's graphic format and the operational characteristics of our web stamp presses.