Development of Color Control System for Offset Printing Press

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In the printing process, one of the most important job is to match color on the printed paper with the proof. So, we have developed a printing color control system with a spectro-measurement sensor and ink key control system, which considers the characteristics of the printing machine. The error of the spectro-measurement sensor is less than 0.1ΔE^* and its efficiency of color control is less than 2.0ΔE^*, minimizing the deviation between a target color and a measurement color. This paper gives an outline of measuring system and ink control system, as well as accuracy of this system, which is confirmed with the MITSUBISHI DAIYA-3 H sheet-feed printing machine.

1. Introduction

The colors of printed matter are usually a mixture of cyan, magenta, yellow and black. Adjustment of color is determined by distribution and feed amount of the color ink, while in the printing machine it is controlled by the ink feed amount mainly. In an offset printing press, however, the color tone varies not only with the ink feed amount, but also with the balance of ink and water, temperature, and operating conditions. Automation of color control is thus difficult, and hitherto it has depended much on the vision and experience of skilled workers.

Mitsubishi Heavy Industries, Ltd. (MHI) has so far developed an ink film thickness/water content meter[(1)] in order to maintain the balance of ink and water in-line, and is confident that stabilized printing can be further enhanced by addition of temperature control of ink rollers. Furthermore, MHI recently developed a system for reducing variations from the target color to a minimum by measuring the color of printed matter with high precision and feeding back as the ink feed amount.

Features of the new system include the following.

- Color measurement precision: spectrophotometer having a performance of color difference[(Note 1)] of $\Delta E^* \leqq 0.1$
- Fast processing circuit finishing measurement in about 15 s[(Note 2)]
- Control to match the target color by spectrum
- Control to adjust ink feed amount according to present printing situation

Moreover, in order to lessen the work load of the system's operators, the user interface is reinforced with features such as an automatic tracking system (up to minimum width of 3 mm) and IPC[(Note 3)] capable of displaying and saving the measured data and trend of the printing state whenever required.

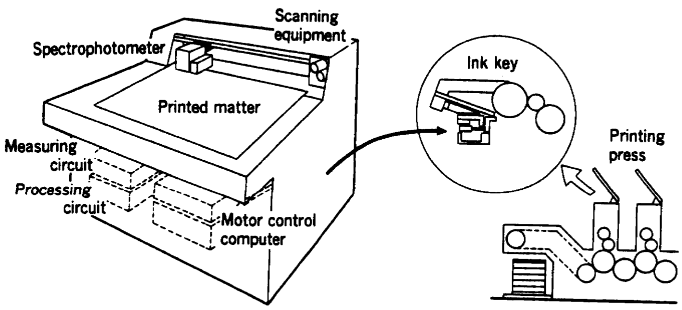

Fig. 1 Outline of color control system for offset printing machines
The color of printed matter is printed, and the variation from the target is adjusted by the ink feed amount.

This report relates particularly to the principal items that realize these features, namely, high speed color measuring apparatus and ink feed amount control algorithm.

(Note 1): Distance between two colors on uniform color space.
(Note 2): Time required for measurement of colors of 182 color scales printed on 939 mm wide paper, calculation of control amount, and display on screen.
(Note 3): Intelligent Press Control.

2. System configuration

2.1 General construction

The general system configuration is shown in **Fig. 1**. Measuring units include a spectrophotometer which measures the colors on the color scale at every wavelength width of 20 nm, and a tracking system that enables this spectrophotometer to track the color scale automatically. These measuring units which are mounted on the scanning device so that they can move in the lateral direction at high speed, scan and measure automatically on the printed matter that is kept in contact with the ink console by vacuum suction. The measured data is processed by the control software in the IPC, and the ink feed amount is calculated, displayed, and adjusted automatically after approval by the operator. In the IPC, the present printing status (speed, number of printed sheets, etc.) is collected at the same time.

2.2 Hardware configuration

The hardware may be roughly divided into the spectrophotometer, and automatic tracking system.

2.2.1 Spectrophotometer

The spectrophotometer is required to have high speed and a small measuring diameter, as well as being high accuracy. In particular, the smaller measuring diameter is needed not for color matching by the color scale on the printed matter, but for minimizing the control strip width on the sheet. Accordingly, an original spectrophotometer having the following measures has been developed.

The general construction is shown in **Fig. 2**. The light source is a halogen lamp with stable amount of light; dark correction is performed by the shutter for every measurement. The sensor head is of separate type in view of size reduction, and the annular photo-receiver collects light with high effi-

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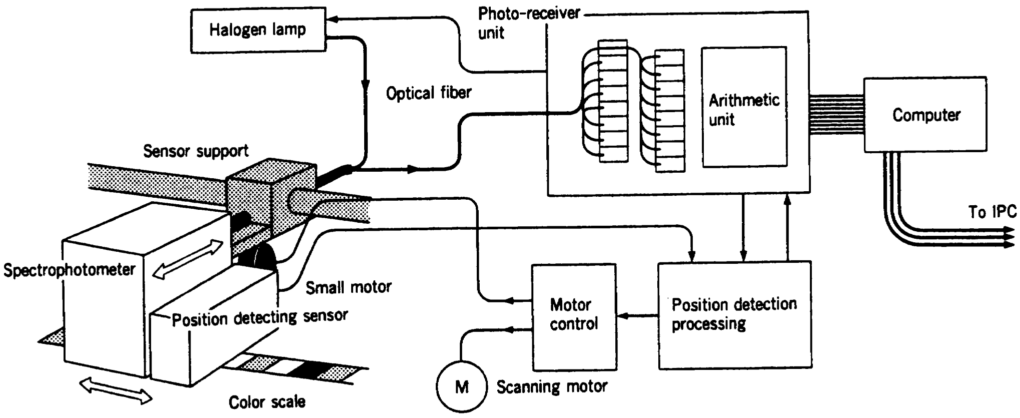

Fig. 2 Construction of hardware
The hardware is composed of a circuit for measuring the spectrum and a circuit for detecting position.

ciency.

The light obtained in the sensor head is sent to the receiver through a coaxial optical fiber of illuminant and detection. The receiver integrally incorporates a PIN type photo diode, interference filter, and fiber coupling, and 16 units are arranged in parallel for dividing 400 to 700 nm by 20 nm pitch. The output is A/D converted by 16 bits.

2.2.2 Automatic tracking system

In a narrow color scale, it is hard to adjust the spectrophotometer within a specific width. It is therefore automated by a small motor for positioning with a position detecting sensor.

The sensor for detecting position is a color CCD that is capable of detecting in a scale containing other colors than the four primary printing colors (cyan, magenta, yellow, and black). The tracking range of this system is ±10 mm from the center of the color scale width; the operator has only to adjust the color scale roughly in the position reference LED, and automatic measurement is performed. In addition, since the position detecting sensor reads the information of color scale in advance, and the changing point of every color is detected, measurement by one-way scanning is conducted.

2.3 Software configuration

The control software automatically controls the ink feed amount on the basis of the spectral reflectivity measured by the spectrophotometer. Its flow is shown in **Fig. 3**. Its main feature is the fact that it calculates the ink feed amount from the spectral reflectivity and not from the color coordinates. When color coordinates are not used, there is hardly any effect of ambient light and observation viewing field, so that advanced color coincidence can be expected. Moreover, halftone dot color control is realized by selecting the solid line arrow in Fig. 3, or solid color control is possible by selecting the dotted arrow. Furthermore, the function of color matching formed of special color components is also featured, and almost all colors printed by the printing machine are covered.

3. Color measuring system

As mentioned in chapter 2, high speed and small measuring diameter are required in the spectrophotometer. The design value of color measuring time is 5 s, which means that measurement of one color must be finished in 5 ms. Supposing that the minimum color scale width is 3 mm, the measuring

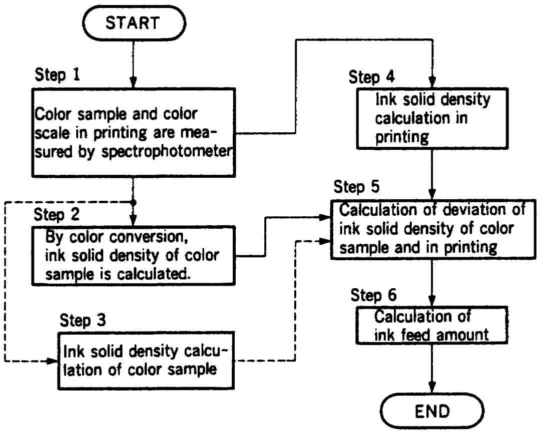

Fig. 3 Control flow diagram
This diagram shows the flow of color control.

diameter is 2 mm. In order to obtain the required measuring precision while satisfying these conditions, it is necessary to utilize the diffusion reflected light on the printing sheet to the maximum availability.

3.1 Illuminating and detecting unit

In the case of one light source, as shown in **Fig. 4**, the most efficient method is to project the light from the vertical direction and detect from the whole circumference in a 45° direction. For illumination, the light from the fiber is accurately focused in a diameter of 2 mm by precision-optimized achromats lens corrected of aberration. At the same time, to prevent excess reflection from the inner wall of the sensor head lens-barrel, the inner wall structure is optimized by ray tracking simulation. To detect the light, 16 fibers having tiny lens attached to their ends are arranged on the circumference to enhance efficiency.

3.2 Spectral unit

Spectral elements include dispersion elements such as grating, and band-pass elements such as interference filters. However, the gratings have larger light loss, and the device size is larger than bandpass elements in order to cut off high-harmonic diffract light. Hence, interference filters are attached to each of the 16 detecting fibers, and a simple structure with small loss is realized. The interference filters had the full width at half maximum of 15 to 20 nm, maximum transmissivity of over 70%, and high-harmonic shielding of less than 0.1% as

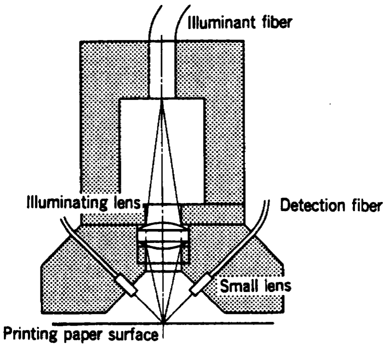

Fig. 4 Magnified appearance of sensor head
Light emitted from the vertical direction is diffused and reflected on the printing paper, and the reflected light is received by the lenses arranged on the circumference.

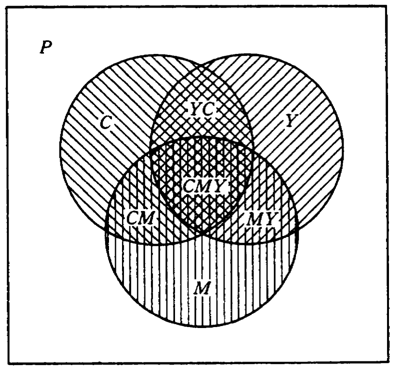

Fig. 6 Resulting colors in three-color halftone printing
Composite color composed of dots of cyan *C*, magenta *M* and yellow *Y* appears to be gray.

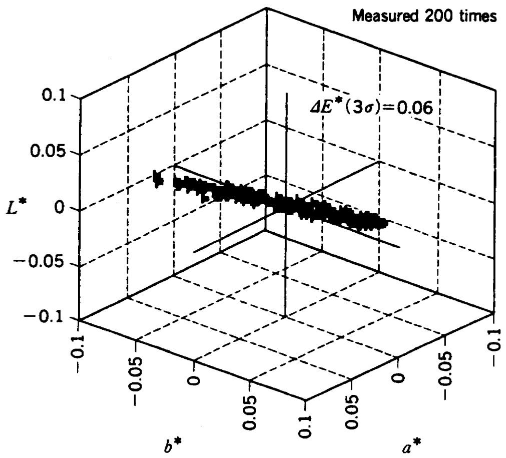

Fig. 5 Accuracy of spectrophotometer by CIE $L^*a^*b^*$ color space
Sensor outputs when measured 200 times continuously on standard white board are shown on $L^*a^*b^*$ color space.

transmissivity. A coupling lens for prevention of loss was inserted between each interference filter and fiber.

3.3 Accumulating unit

The photo-receiving elements are inversely biased PIN photo diodes, but they are not of storage type. Accordingly, a capacitor is installed behind each photo diode, and the output charge is accumulated for 5 ms and read out at high speed. By this circuit design, high sensitivity detection is realized and only one A/D converter is required.

3.4 Verification of precision

At the measuring time of 5 ms, the result of color measurement by measuring 200 times continuously on a standard white board is shown in **Fig. 5**. Supposing the standard deviation from the mean chromaticity to be an error, precision of color difference $\Delta E^* \leqq 0.1$ is obtained.

4. Control software

Automatic ink key control necessitates determining the ink feed amount corresponding to color difference between printed paper and the proof.

In Fig. 3, when solid colors are controlled, the solid color difference in printing can be measured by the spectrophotometer directly, and it is proportional to ink film thickness, i.e. ink feed amount. When matching three color halftone, however, the halftone measurement must be converted to the single solid color.

This conversion requires determining the halftone area rate of color scale in printing, trapping parameter, and relation between spectral reflectivity and ink solid density. The conversion method is described below.

4.1 Control algorithm

Printed matter is composed of tiny dots of cyan, magenta, yellow, and black inks. The human eye cannot distinguish the individual colors of dots, but perceives them as composite color, such as the gray in **Fig. 6**. In Fig. 6, dots of cyan ink are expressed as *C*, magenta as *M*, and yellow as *Y*. Therefore, the gray color in the diagram, apart from the individual color dots, is composed of the *C* and *M* mixed portion *CM* and, similarly, *MY*, *YC*, *CMY*, and paper portion *P*.

According to the theories of Neugebauer[2] and Demichel[3], the spectral reflectivity of composite color is equal to the sum of contributions from the spectral reflectivity of each component color, and is expressed in the equation below, supposing the dot area rate of cyan to be c, magenta to be m, and yellow to be y.

$$\begin{aligned} R(\lambda) = &(1-c)(1-m)(1-y)R_p(\lambda) \\ &+c(1-m)(1-y)R_c(\lambda)+m(1-y)(1-c)R_m(\lambda) \\ &+y(1-c)(1-m)R_y(\lambda)+cm(1-y)R_{cm}(\lambda) \\ &+my(1-c)R_{my}(\lambda)+yc(1-m)R_{yc}(\lambda) \\ &+cmyR_{cmy}(\lambda) \end{aligned} \quad (1)$$

The individual spectral reflectivities are composite color $R(\lambda)$, cyan $R_c(\lambda)$, magenta $R_m(\lambda)$, yellow $R_y(\lambda)$, cyan and magenta $R_{cm}(\lambda)$, magenta and yellow $R_{my}(\lambda)$, yellow and cyan $R_{yc}(\lambda)$, cyan, magenta and yellow $R_{cmy}(\lambda)$, and paper $R_p(\lambda)$. Herein, λ corresponds to 16 wavelengths of the spectrophotometer.

For color conversion, firstly, the spectral measurements of color scale in printing are inserted into eq. (1), and the dot area rates of the colors c, m, y are determined by an analytical technique such as approximation of least squares.

Next, introducing the trapping parameter[4], overlaid colors are separated into single colors. For example, the composite color spectral reflectivity of cyan and magenta $R_{cm}(\lambda)$ is expressed in the following eq. in terms of the cyan spectral reflectivity $R_c(\lambda)$, magenta $R_m(\lambda)$, and paper $R_p(\lambda)$.

$$R_{cm}(\lambda) = \left(\frac{R_c(\lambda)}{R_p(\lambda)} \cdot \frac{R_m(\lambda)}{R_p(\lambda)}\right)^{t_{cm}(\lambda)} R_p(\lambda) \quad (2)$$

where $t_{cm}(\lambda)$ is the trapping parameter of cyan and magenta.

The relation between the color spectral reflectivity and ink solid density is approximated in eq. (3). An example of cyan is shown herein.

$$\log_{10}\frac{R_p(\lambda)}{R_c(\lambda)} = k_c(\lambda) D_c \quad (3)$$

where $k_c(\lambda)$ is a coefficient of linear approximation. The cyan ink density D_c is expressed as follows:

$$D_c = \log_{10}\left(\frac{\Sigma R_p(\lambda) F_c(\lambda)}{\Sigma R_c(\lambda) F_c(\lambda)}\right) \quad (4)$$

where $F_c(\lambda)$ is the spectral transmittance of red filter, and Σ means to integrate over 16 wavelengths.

Hence, in eq. (1), the unknown are only ink solid density D_c (cyan), D_m (magenta), and D_y (yellow), and the ink solid density of each color coinciding with the spectral measurement of color sample is determined by an analytical technique such as approximation of least squares.

The ink solid density of a specific color D_s is similarly determined by supposing the dot area rate in eq. (1) to be 1.

4.2 Control technique

Referring to the control flow in Fig. 3, the operation at each step is briefly described below.

Step 1: Measurement of R, R_c, R_m, R_y, R_{cm}, R_{my}, R_{yc}, R_{cmy}, and R_p in color sample and color scale in printing.

Step 2: Conversion of the composite color R of color sample formed by halftone dots according to the above algorithm into single solid color D_c, D_m, D_y, from eq. (1).

Step 3: Determining individual color ink solid density D_c, D_m, D_y, and D_k (solid black density) from eq. (4), in the case of solid color mixing.

Step 4: Determining individual color ink solid density in printing D_c', D_m', D_y', D_k', D_s', from eq. (4).

Step 5: Determining the deviation of individual color ink solid density of target color sample and the ink solid density in printing in eq. (5).

$$\left.\begin{array}{l} \delta D_c = D_c - D_c', \ \delta D_m = D_m - D_m' \\ \delta D_y = D_y - D_y', \ \delta D_k = D_k - D_k' \\ \delta D_s = D_s - D_s' \end{array}\right\} \quad (5)$$

Step 6: Controlling the ink feed amount of the printing machine automatically by preliminarily investigating the relation between the density deviation δD and changing the ink feed amount in the printing machine.

5. Result of verification result in printing machine

This spectral color control system was incorporated in Mitsubishi DAIYA-3 H sheet-fed printing machine, and its performance was verified.

In color coincidence evaluation, the spectral reflectivity was converted into color coordinates ($L^*a^*b^*$), and the color difference ΔE^* was determined.

The target of control performance was the normal human color distinguishing capability of about $\Delta E^* \leqq 2$.

The conditions of verification were as follows.

(1) Printing is sampled in every 70 sheets, the color scale is measured, and the ink feed amount is adjusted automatically.

(2) The colors used in verification are the gray portion formed of cyan, magenta and yellow dots, and the violet portion formed by a specific solid color.

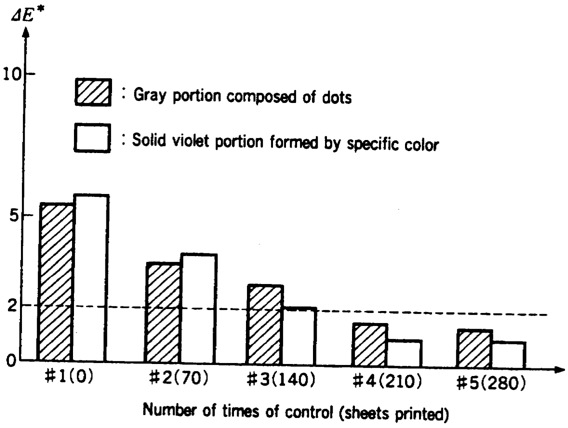

Fig. 7 Result of inspection
Results of color control obtained by installing the spectral color control system in a printing machine.

As can be seen from **Fig. 7**, at the third adjustment, i.e., the 210th sheet, it was confirmed through verification that the variation from the target color converges at less than $\Delta E^* \leqq 2$. Considering that a skilled operator requires from 100 to 500 sheets to achieve this color control, this performance may be evaluated as color control skill equivalent to that of an experienced operator or better.

6. Conclusions

We have developed a system for numerical control of color evaluation of printed matter which has hitherto depended on the experience of skilled operator, by evaluating objectively, and for controlling the ink keys automatically on the basis of obtained results.

This system marks one step toward development of a new printing machine usable by any operator, replacing conventional printing machines that depend greatly on the skill and experience of operators. The system is also expected to help skilled operators considerably in the performance of printing tasks.

Whether in solid density control or in three-color halftone control, in order to utilize this system effectively, exposure control of plates in prepress and dot gain control in printing are important.

In the printing industry, standardization is being promoted from the upstream process, and it is also necessary to cope with this trend in the printing process.

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