Offset Print Analysis with Mathematical Regression Model

[1]Nandakumar M., [2]Bose N.

[1] *Arasan Ganesan Polytechnic College, Sivakasi, India*

[2] *Mechanical Engineering, Mepco Schlenk Engineering College, Sivakas, Indiai*

Abstract

The objective of this study is to analyze and compare the print quality by offset printing process on uncoated paper for matching the quality on par with ISO 12647 standards. A standard test form that contains different control strips for densitometric and colorimetric measuring has been used to define the optical density and color difference of the main process ink colors like cyan, magenta, yellow and black while printed on four-color Heidelberg CD102 sheet-fed offset printing press. The results are important from scientific and practical point of view. By applying the regression analysis methods, the correlation between the optical density deviations ΔD from the optimal values and color difference ΔEab represented by the following regression model of Quadratic equation: $\Delta Eab = a + b\Delta D + c\Delta D^2$ ($y = a + bx + cx^2$) has been ascertained. By using the mathematical regression model, identification of the suitable values of every color on the output in offset printing, can be easily done. The experimental result of print density and LAB values on uncoated paper is matching with ISO 12647-2 Graphic technology – process for the production print.

Key words: Print Quality, Offset Printing, Substrate, Optical Density, Dot Gain, Color Difference, Color Deviations, Regression Model, Control strips.

1. Introduction

The basic principle of offset printing is simple: ink and water do not mix. When the metal plate is exposed, an ink receptive coating is activated at the image area. On the press, the plate is dampened; initially by water rollers, then by ink rollers. The ink adheres to the image area and the water adheres to the non-image area. As the cylinders rotate, the image is transferred to the rubber blanket. The substrate passes between the blanket cylinder and the impression cylinder, where the image is transferred onto the substrate [1]. A great number of quality parameters are defined in the International standards. In offset printing process we operate with parameters like ink quantity, registration of colors, water/ink balance and pressure in printing zone [2]. Uncoated papers are more absorbent of ink than a coated paper. It is generally not as smooth as coated paper and tends to be more pored. These pores contribute to rapid ink penetration and large pores act as the solvent storage. Most types of uncoated paper are surface sized to improve their strength [3]. ISO 2846-1 Graphic technology color as well as transparency of ink sets for four color printing is the internationally recognized standard for offset lithographic printing processes [4]. ISO 12647-2 is the only official international printing standard which specifies a number of process parameters to be applied when preparing color separations for four color offset printing by means of four-color offset lithographic processes [5].

2. Experimental Setup

This paper aims at arriving a mathematical analysis and equation on relating the print density and color parameters printing on uncoated paper by offset printing process. Standard color control strips and elements of solid patches for Cyan, Magenta, Yellow, Black, two color overprint patches, 40% and 80% dot gain patches, slur/doubling control elements, registration marks. During the experiments CtPlates four color positive working printing plates, TOYO-Leoman process inks, 110 g/m² uncoated papers and four color sheet-fed Heidelberg CD 102 were used.

A spectrophotometer/densitometer of type Xrite Spectro-Eye has been used for measuring of optical density and the color characteristics in the CIE Lab color space. Average color characteristics of used papers measured on five different places were in accordance with ISO12647-2 tolerances L±3, a±2, b±2. A series of samples were characterized by gradual smooth changes of ink quantity – from under-inking to over inking. In order to express the analytical dependence between ΔD and ΔEab, it is necessary to apply mathematical modeling, regression analysis and statistical analysis of experimental data, taking into consideration the deviation and variation tolerances from optimal inking for C, M, Y and K. It was determined, that the experimental fitting curve is a parabola, described with the formula: $y = a + bx + cx^2$ in this specific case $\Delta Eab = a + b\Delta D + c\Delta D^2$.

3. Results and Discussion

Density measurements of solid ink patches were used to monitor the ink film thickness applied during a press run. In comparing two printed sheets, density readings should be within 0.05 units, when measured on a Spectrophotometer, for meaningful print quality assessment [6]. The density value of offset printing on uncoated paper was measured with Xrite SpectroEye spectrophotometer. The measured density value for different colors of C, M, Y and K for uncoated paper is given in Fig. 1.

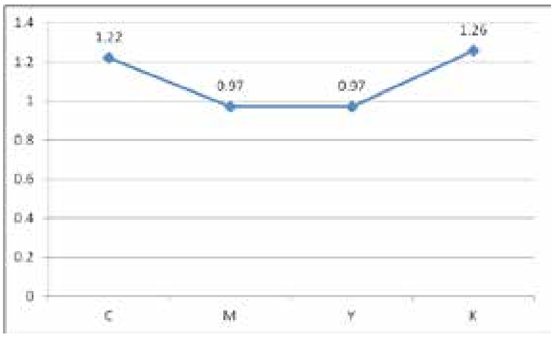

Fig. 1. Density values of uncoated papers

The solid ink density is a function of the percentage of light reflected. From Fig. 1 it is observed that reflection density of the offset printed sheets on uncoated paper of Cyan is 1.22, for Magenta 0.97, for Yellow 0.97 and for Black 1.26.

3.2 Color parameters CIE LAB values

Assessment of color is more than a numeric expression. Usually it's an assessment of the color difference delta from a known standard. CIELAB is used to compare the colors of two objects. Given the ΔL* Δa* Δb* values, the total difference or distance on the CIELAB diagram can be stated as a single value, known as ΔE*ab [7].

$$\Delta Eab = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2}$$

The CIE LAB values measured in offset printing of uncoated paper for different color inks of C, M, Y and K using Xrite spectrophotometer is given in Table 2 & 3 and graphically represented in Fig. 2.

It is observed from the Table 1 that the color difference of cyan ΔEab is 2.36, magenta ΔEab is 1.78, Yellow ΔEab is 2.64 and black ΔEab is 0.36. The deviation tolerance as per ISO standard for offset printing of each color is 5 and the differences are within the prescribed value. Hence the LAB value of uncoated paper shows equally good quality of color reproduction compared with ISO standard value. It is observed from the Table 2 that the color difference of Magenta on Yellow print ΔEab is 2.06 for Cyan on Yellow color overprint ΔEab is 2.06 and for Cyan on Magenta overprint ΔEab is 2.30. The color differences are within the range of 5 as represented graphically in Fig. 2. Hence the consistency of the print quality is assured in uncoated paper.

The plotted values of CMYK are not deviating from the OK print of the production run samples color values. The plotted readings of cyan, magenta, yellow and black production prints optical density values are within the variation tolerance as specified in ISO-12647 standard. The half of 4 is 2 for cyan, magenta and black colors. For the yellow color it is 2.5 and the variation tolerances are acceptable. The regression model for cyan, magenta, yellow and black colors optical density ΔD against the color parameters ΔEab is within the tolerance value.

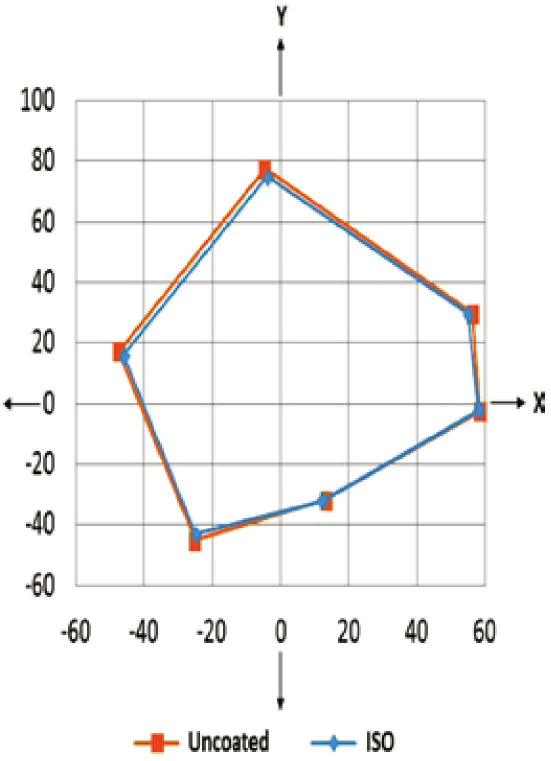

Fig.2 LAB values of uncoated paper [X axis CIELAB red-green coordinate a*] [Y axis CIELAB yellow-blue coordinate b*]

Table 1 LAB Values – for process colors C, M, Y and K on uncoated paper

Color		ISO	Uncoated	ΔEab
C	L*	58.0	59.2	2.36
	a*	-25.0	-25.13	
	b*	-43.0	-45.03	
M	L*	54.0	55.67	1.78
	a*	58.0	58.38	
	b*	-2.0	-2.5	
Y	L*	86.0	87.02	2.64
	a*	-4.0	-4.62	
	b*	75.0	77.36	
K	L*	31.0	31.3	0.36
	a*	1.0	1.2	
	b*	1.0	1.04	

Table 2 LAB Values – for additive colors R, G and B on uncoated paper

Color		ISO	Uncoated	ΔEab
R (M+Y)	L*	52.0	53.60	2.06
	a*	55.0	56.21	
	b*	30.0	29.72	
G (C+Y)	L*	52.0	52.84	2.06
	a*	-46.0	-47.39	
	b*	16.0	17.27	
B (C+M)	L*	36.0	37.93	2.30
	a*	12.0	13.22	
	b*	-32.0	-31.74	

4. Mathematical modeling to characterize solid ink density and color parameters

Mathematical modeling describes the different aspects of the real world, their interaction, and their dynamics through mathematics. Mathematical models also offer new possibilities to manage the increasing complexity of technology [8]. In this paper, a mathematical model is derived to have a deeper understanding of the relationship between the ink density and color values which determine the print quality on uncoated paper. The ink density ΔD for different values of ΔEab were calculated for determining a mathematical relationship between them to:

i. predict the value of ΔEab based on the value of ΔD
ii. explain the impact of changes in the values ΔEab on the values of ΔD. A regression model is applied to find the relationship between the ink density and color values.

Out of the two variables density variation ΔD and color difference ΔEab, ΔEab is considered as the dependent variable and ΔD as the independent variable. Using regression model, it is studied that changes in the values of dependent variable are resulted by the changes in the values of independent variable. Regression model polynomial parabola curve fit is used in this paper to arrive the mathematical model. The relationship between ΔD and ΔEab is represented by the polynomial parabola fit is given by $\Delta Eab = a + b\Delta D + c\Delta D^2$. Fitting a model means obtaining the values of the parameters a, b and c on the basis of collected observations on ΔD and ΔEab.

5. Analysis of the regression model and Discussion

The OriginPro 8 SR4 version software is used in this research for curve fitting using regression analysis to find the relationship between ink density ΔD and color parameters ΔEab. Origin is an industry-leading scientific graphing and data analysis GUI software developed by OriginLab®. Curve fitting is one of Origin's most powerful and most widely used analytical methods. Origin provides tools for linear and nonlinear curve fitting. The output data of printed sheet results are assessed by feeding the readings of Cyan, Magenta, Yellow and Black density readings ΔD and ΔEab color differences to find the best fit regression model. A regression model is first developed, and then the best fit parameters are estimated using the least-square method. Finally, the quality of the model is assessed using hypothesis tests of R^2, T-value and F-value of ANOVA to ascertain the fitness of the regression model. The regression model equation, estimated R^2, T-statistics and F-test ANOVA of the data for uncoated is shown in Table 3 and plots of the CIE LAB values of C, M, Y and K are shown in Fig. 3.

In X axis the ΔD optical density and Y axis ΔEab color parameters are taken, the readings were fitted in the regression line for all four process colors. The individual measured values of ΔD and ΔEab of Cyan, Magenta, Yellow and Black readings were plotted in the regression equation shown in the graph. The different readings of printed samples were assessed for their quality reproduction and OK print samples were considered for the analysis of density color difference on uncoated paper.

Table 3 Regression Model for Uncoated paper

Ink	Mathematical model (Regression)	R2	F (ANOVA)	T-statistics
Cyan	$\Delta E = 1.23899 - 9.48388\ \Delta D + 599.06023 \Delta D^2$	0.90552	241.84096	7.38924
Magenta	$\Delta E = 1.20154 + 1.25273\ \Delta D + 1155.03714 \Delta D^2$	0.94968	454.47028	7.35956
Yellow	$\Delta E = 1.74978 + 0.94668\ \Delta D + 1566.22125 \Delta D^2$	0.93953	353.20034	7.07146
Black	$\Delta E = 0.63296 - 1.70439\ \Delta D + 215.49149 \Delta D^2$	0.95568	785.03328	8.9765

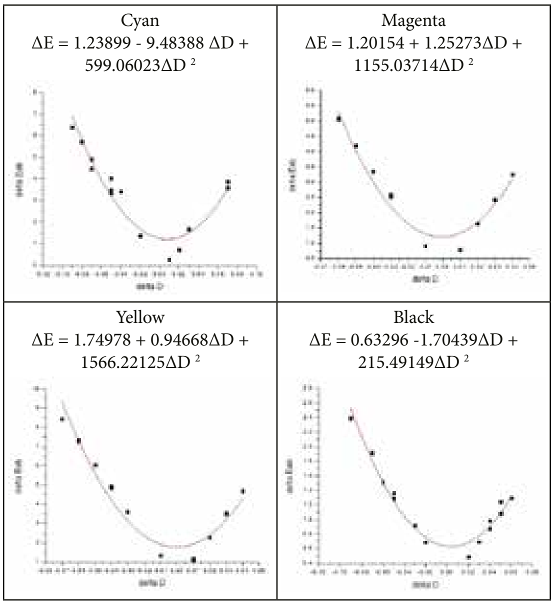

Fig. 3 Graph showing the scatter plot and fitted lines for uncoated paper

In the regression model $y = a + bx + cx^2$, 'a' is the y-intercept and 'b' is the slope. From these experimental values and mathematical models it is studied that the slope is normal for all CMYK process colors. It shows that there is a linear relationship between optical density and color values.

5.1 Goodness-of-fit

Linear regression calculates an equation that minimizes the distance between the fitted line and all of the data points. Technically, ordinary least square regression minimizes the sum of the squared residuals [9]. In general, a model fits the data well if the differences between the observed values and the model's predicted values are small and unbiased. The fitness of the model can be proved using the following parameters:

1. Coefficient of determination (R^2)
2. t-test statistics
3. F-test (ANOVA)

5.2 Coefficient of determination

The goodness of the fitted model is studied by calculating the Coefficient of determination R^2. R^2 is a statistical measure showing the closeness of the data to the fitted regression line. R^2 is the percentage of the response variable variation that is explained by a linear model.

R^2 = Explained variation / Total variation

$$R^2 = \frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}$$

R^2 is always between zero and one. Zero indicates that the model explains none of the variability of the response data around its mean and One indicates that the model explains all the variability of the response data around its mean. In general, the higher the R-square, the better the model fits the data. From Table 3, it is clearly noted from the experimental results that for uncoated paper R^2 is calculated for cyan is 0.90552, Magenta is 0.94968, Yellow is 0.93953 and for black it is 0.95568. As stated earlier the R^2 for uncoated paper values of CMYK are very close to the 1 and hence the mathematical models arrived are considered to be fitted model.

5.3 t-Test for the slope

The t-value is a statistic test that measures the difference between an observed sample statistic and its hypothesized population parameter in units of standard error. A t-test compares the observed t-value to a critical value on the t-distribution with (n-1) degrees of freedom to determine whether the difference between the estimated and hypothesized values of the population parameter is statistically significant.

For the fitted model, the hypothesis is tested. The slope is zero against H_o:b=0 against H_a:b≠0 is tested [10]. The test statistics is

$$T_c = \frac{\hat{b}}{\sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y})^2}{(n-2)\sum_{i=1}^{n}(x_i - \bar{x})^2}}}$$

The t-test value of uncoated paper results for Cyan, Magenta, Yellow and black were computed and entered in Table 3. The T-statistics for cyan is 7.38924, Magenta is 7.35956, Yellow is 7.07146 and for black it is 8.9765. The T-statistics value at 5 % level of significance and 13 degree of freedom, the critical value referred from the t- distribution Table minimum is 2.160. It is verified from the computed T-Values of CMYK are higher than 2.160. Therefore, at 5% level of significance the null hypothesis is rejected for uncoated paper of all process colors of Cyan, Magenta, Yellow and Black. Hence it is concluded that there is an evidence of linear relationship between the optical density deviations ΔD from the optimal values and color difference ΔEab of print quality on uncoated paper.

5.4 F-Test (ANOVA)

F-test can be used as an alternative for t-test for linearity. In F-test also, the hypothesis H_0 : b = 0 is tested. This test is based on the concept of partitioning the total variability into explained variability and unexplained variability.

$$F = \frac{\sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2\, x}{\sum_{i=1}^{n}(y_i - \hat{y})^2}$$

An F-test is any statistical test in which the test statistic has an F-distribution under the null hypothesis. It is most often used when comparing statistical models that have been fitted to a data set, in order to identify the model that best fits the population from which the data were sampled. Exact "*F*-tests" mainly arise when the models have been fitted to the data using least squares.

The F-test value for uncoated paper of Cyan, Magenta, Yellow and black were computed and entered in Table 3. The F-statistics for the uncoated paper for cyan is 241.84096, for Magenta 454.47028, for Yellow 353.20034 and for black 785.03328. F-value at 5% level of significance and (1, 13) degree of freedom, the critical value using F distribution table is 4.67 which is lesser than the computed values shown in Table 3. Therefore, at 5% level of significance the null hypothesis is rejected and concluded that there is an evidence of linear relationship between the optical density deviations ΔD from the optimal values and color difference ΔEab in print quality on uncoated paper.

6. Conclusion

The experimental research was carried out in real production conditions. The deviation and variation tolerances from optimal inking density values from offset printing outputs on uncoated paper was thus determined, taking into consideration the human optical perception and the specific production conditions. The obtained results for deviation and variation tolerances can be used in practice for quality control of printing process. The experimental results demonstrate that there is correlation of print density and LAB values of the inks on uncoated paper matching with International Standard ISO 12647-2 Graphic technology - Process control for the production of prints. The mathematical regression model also evidently confirms the linear relationship between the optical density deviations ΔD and color difference ΔEab of print quality on uncoated paper by offset printing process. Mathematical regression model can be developed for the specific printing press condition positively and applied in practice effectively for determining quality on sheet-fed offset presses.

Acknowledgement

The authors would like to thank
Mr. Vashikaran Rajendrasingh, Bell Printers, Sivakasi for providing all facility for carrying out our print experimental works.

References

1. Raymond N. Blair, The lithographers manual, Seventh edition, pp. 1:9 – 1:11.
2. Helmut Kipphan, Handbook of Print Media, Springer, Heidelberg, pp. 206-354.
3. NIIR Board of consultants & engineers, Modern technology of pulp, paper and paper conversion industries, pp. 356-410.
4. International Standard, ISO2846-1, Graphic technology Color and transparency of ink sets for four-color-printing.
5. International Standard ISO 12647-2, Graphic technology - Process control for the production of halftone color separations, proof and production prints – Part 2: Offset lithographic processes, pp 1-19.
6. A Guide to Understanding Graphic Arts Densitometry, X-rite manual, pp 1-11.
7. Roy S. Berns, Billmeyer and Saltzman's Principles of Color Technonogy, Third edition, 2000, Wiley-Inter science Publication, pp. 107-130.
8. C.F.Jeff Wu, Michael Hamada, Experiments – Planning, Analysis and Parameter design Optimization, Wiley India, 2002, PP. 135-142.
9. Clive L. Dyn, Principles of Mathematical Modeling, 2nd edition, Academic Press, 2004, pp. 3-12.
10. C.R.Kothari and Gaurav Gard, Research Methodology Methods and Techniques, Third edition, New Age International Publishers, 2014, pp. 312-331.