Determination of the Deviations and Variations Tolerances of the Process-Colour Solids from the OK Print in Offset Printing Method

Iskren Spiridonov

Keywords: Print Quality, Offset Print, Optical Density, Colour Difference, Deviations and variations tolerances

The goal of the present study is to define the correlation between the optical density and colour difference of the main process ink colours cyan, magenta, yellow and black on two different types of paper, printed on four-colour sheet-fed offset printing press. A test form has been used that contains different control strips for densitometric and colourimetric measuring. By the methods of Regression analysis, it has been ascertained that the correlation between the optical density deviations - ΔD from the optimal values and colour difference - ΔEab, can be presented by the following regression model (equation): $\Delta Eab = a\Delta D^2 + b\Delta D + c$ ($y = ax^2 + bx + c$). The experimentally obtained coefficients are not equal for the different paper-ink combinations, which suppose different limits for ΔD. By using the defined in ISO standards limits for colour difference ΔEab, it can be defined which ΔD limit values correspond to every colour and every paper-ink combination. The results achieved are important from scientific and practical point of view. For the first time in an experimental way a well-grounded proof has been achieved with regard to the limits of the optical density deviation and variation from the optimal values for various ink-paper combinations, by provision of colour differences in compliance with the international standards.

1. Introduction

The quality of printing production is the most important factor, which determines the market position of the printing houses. A big number of quality parameters are defined in the International standards. In offset printing process we operate with parameters like ink quantity, registration of colours, water/ink balance, pressure in printing zone, etc. Quality of printing image is function of supporting of printing process parameters in precise boundaries.

In the practice we use two methods to measure the quantity of printing ink and quality of printed images:

Densitometric methods – used for control and management of printing processes [1, 2, 3], based on measurement of optical density, tone values, tone value increase and derived quality parameters like relative print contrast, ink trapping, etc.

Colourimetric methods – based on measurement [1, 3, 4, 5, 6] of colour coordinates values and colour differences ΔEab.

All the two methods have advantages and disadvantages [3]. While colourimetric measurements are based on techniques where colours are measured as they are perceived by the human eye, densitometric techniques are basically a measurement of ink film thickness that has been adapted to the inks used in the print, and where the processing of the measuring values is adapted to human perception/sensitivity in relation to changes of lightness/saturation with varying ink film thicknesses.

The idea for obtaining a mathematical model and connection between ΔEab and ΔD was borrowed from standard ISO 2846-1. This standard [6] offers a method for graphical determination of the colorimetric conformance of inks. This conformance is achieved by calculating the colour difference (ΔEab) from the reference values for each of the prints made and plotting this against the ink film thickness. Implementation of this method, but for finding a mathematical connection (model) between reference colour values of process ink sets from ISO 12647-2 [6] and specified in standard tolerances for ΔEab, will give an admissible ΔD tolerances. These ΔD tolerances could be implemented in practice and no spectrophotometer for measuring of colours and ΔEab will be needed. There is a

formula used by spectrophotometers to provide information for optical density from colour coordinates of the measured patch, but there is no possibility without experimental research for specific and different combinations of paper type – inks – printing press to obtain a correct simulation of the values of colour coordinates (respectively optical density).

In other papers [7, 8], authors have been made analyses and researches about connection between densities and colour differences, but for different purposes and they are using different methodologies.

2. Experimental

The main goals of this research is to define the correlation between optical density and colour difference of basic process inks colours – cyan, magenta, yellow and black in printing on two types of paper – glossy coated paper and uncoated paper, on four colour sheet-fed offset printing press. The test form that have been used contains different control strips and elements: solid patches for C, M, Y, K, two colour overprint patches, 40 % and 80 % dot gain patches, slur/doubling control elements, registration marks, etc. All measuring components are with screen ruling value 60 cm^{-1}.

During the experiments were used positive working printing plates exposed on CtPlate system Lüscher XPose 130. The offset printing press, which has been used, is five colour sheet-fed Heidelberg Speedmaster 74. The paper, which has been used, is 150 g/m² coated glossy paper (Neo gloss), and 80 g/m² uncoated paper (Amber offset). The inks, used in experiment were tested in and they conforms to ISO 2846-1 [6] (all standard requirements for colour, transparency and ink film thickness range). The inks printing sequence is K, C, M and Y.

A spectrophotometer/densitometer of type SpectroEye of GretagMacbeth has been used for measuring of optical density and the colour characteristics in the CIE Lab colour space. All measurements are in accordance with ISO 12647-1[2]: D50 illuminant, 2° observer, 0/45 or 45/0 geometry, black backing and in accordance with ISO standards [9, 10, 11]. Colour characteristics (averaged) of used papers (print substrate colour) measured on five different places are in accordance with ISO 12647-2 [4] tolerances (L±3, a±2, b±2).

In the above-mentioned conditions were printed series of samples characterized by gradual smooth changes of ink quantity – from under-inking to over-inking. When the test samples are printed, by method of maximum printing contrast [1] was determined the optimal quantity of printing inks (presented by Dv) for the two types of papers. The experimental defined values of Dv are shown in Table 1.

Table 1: Experimental defined values for optimal quantity of printing ink for the two types of paper

Type of paper	Dv (optical density of 100% solids)			
	Cyan	Magenta	Yellow	Black
Glossy coated paper	1.57	1.59	1.46	1.85
Uncoated white paper	1.07	1.07	0.95	1.25

Table 2: CIELAB ΔEab tolerances for the solids of the process colours

Parameter	Process Colours			
	Cyan	Magenta	Yellow	Black
Deviation Tolerance	5	5	5	5
Variation Tolerance	4	4	5	4
½ of Variation Tolerance	2	2	2.5	2

From the already printed sheets fortuitously were taken printed sheets, which have not a slur/doubling or other print defects. For the each type of papers and for all process ink colors were defined the reference colour patches – these are the fields, which have an optimal density values (Table 1). For the each type of papers and process colours were performed a big number of measurements from under-inking to over-inking of CIE Lab color values and optical densities - Dv. The numbers of measurements for each paper and ink colours were different and it have been determined from obtaining of big variety of colour differences – from minimum up to in excess of determinate limits of colour differences tolerances defined in Table 2. The main goal of this research is formulated on the base of the advantages and disadvantages of the densitometry and colourimetry, as follows: to determine the dependence between the optical densities and the colour differences of the basic ink colours.

The current version of ISO 12647-2 has defined the following admissible deviation and variation tolerances as follows in Table 2 [4].

The deviation of the process-colour solids of the OK print of the production run is restricted [4] by the condition that the colour differences between proof and OK print shall not exceed the deviation tolerances specified in Table 2.

The variability of the process-colour solids in production is restricted [2] by the following condition. For at least 68 % of the prints, the colour differences between a production copy and the OK print shall not exceed, and should not exceed one half of, the pertinent variation tolerances specified in Table 2.

During previous research [12], the relation between ΔD and ΔEab was investigated in accordance with reference values, as set by the previous ISO standard version. In order to express the analytical dependence between ΔD and ΔEab, it is needed to apply mathematical modeling, regression analyses and statistical analyses of experimental data, taking into consideration the deviation and variation tolerances from optimal inking for C, M, Y, K, considering to the data in Table 2.

It was determined, that the experimental fitting curve is a square function – parabola, described with the formula: $y=ax^2+bx+c$ (in this specific case – $\Delta Eab=a\Delta D^2+b\Delta D+c$). After experimental data analyzes, for some of the cases the coefficient b was omitted (the methodology is described below in the text). Therefore the function type was transformed to: $y=ax^2+c$ (in this case – $\Delta Eab= a\Delta D^2+c$).

3. Results and Discussion

Results of the measurements are shown in following graphics. On x-axis is projected deviations ΔD from the optimal ink quantity expressed by Dv and on y-axis colour difference ΔEab from the reference value.

The one of the most important part of this research, that guarantee formulation of realistic and practically applicable model - ΔEab= f(ΔD) is methodology and mechanism for obtaining the mathematical models and their statistical analyses. That's why in the following part of paper, there is applied a short description of it.

The experimental data sets are shown only graphically on Figures 1–4 and the statistical analyses of regression models are not included, because it will be obtained an unnecessary and significant rising of the paper volume.

A regression analysis is statistical approach for defining a mathematical model, which describes connection between two or more parameters. The main goal of the regression [13] in this case is obtaining and analysis of the regression equations (Formula 1), based on experimental results.

$$\hat{y}=\sum_{i=1}^{k} b_i f_i(\vec{x})=\mathbf{bf(x)} \qquad (1)$$

where $\hat{y}$ is the predicted value of output value, $\mathbf{b}=(b_1,b_2,\dots,b_k)$ k-dimensional vector of unknown coefficients, $\mathbf{f}=[f_1(\vec{x}),f_2(\vec{x}),\dots,f_k(\vec{x})]$ k-dimensional vector-function of factors $\mathbf{x}=(x_1,x_2,\dots,x_n)$. Elements $\mathbf{f_i(x)}$, $\mathbf{f(x)}$ are called repressors. In big number of cases the equation (1) has polynomial type of first or second degree [14].

Software products Minitab v.14 and OriginPro v.7.5 have been used for building of mathematical models and analyses of data. A regression models and their analyses [15] have been performed by the following methodology – steps A, B, C, D.

One of the most important conditions, that guarantee formulation of realistic and practically applicable model - ΔEab= f(ΔD), is the statistical analyses of the regression model [13, 16, 17]. The analyses has been made in several steps:

Step A. Dispersion analyses

Dispersions of values of output parameters - y around the defined mean value. That is characterized with total sum of squares (Formula 2), which is caused by two reasons – influence of regression model and influence of residual error and potential inadequacy of the model.

$$Q_0=\sum_{u=1}^{N}(y_u-\bar{y})^2 \qquad (2)$$

The total sum of squares is based on sum of regression sum of squares and residual sum of squares. It is calculated by Formula 3.

$$Q_0=Q_R+Q_{res} \qquad (3)$$

where

$$Q_R=\sum_{u=1}^{N}(\hat{y}_u-\bar{y})^2 \qquad (4)$$

is regression sum of squares, and

$$Q_{res}=\sum_{u=1}^{N}(y_u-\hat{y}_u)^2 \qquad (5)$$

is residual sum of squares.

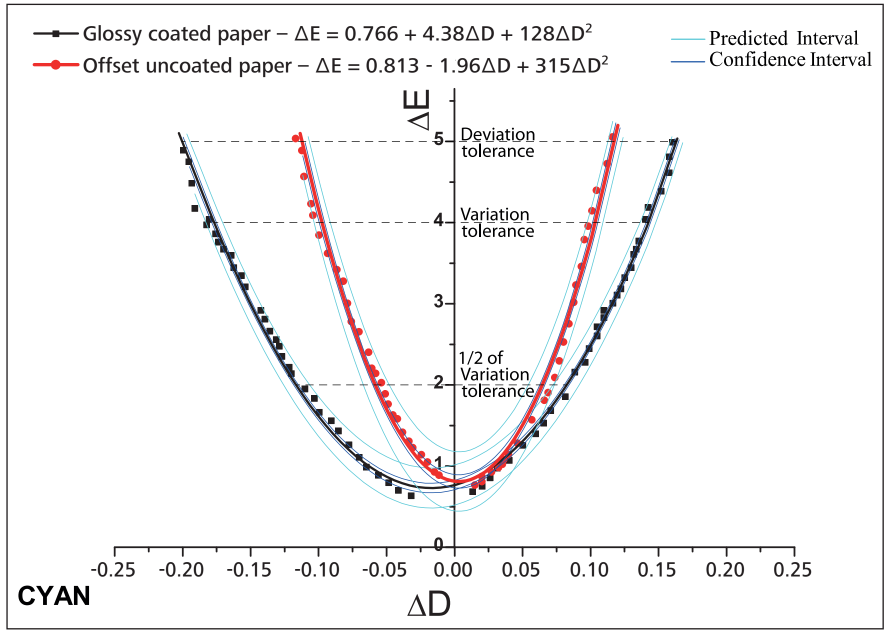

Figure 1: ΔD – ΔE function for Cyan

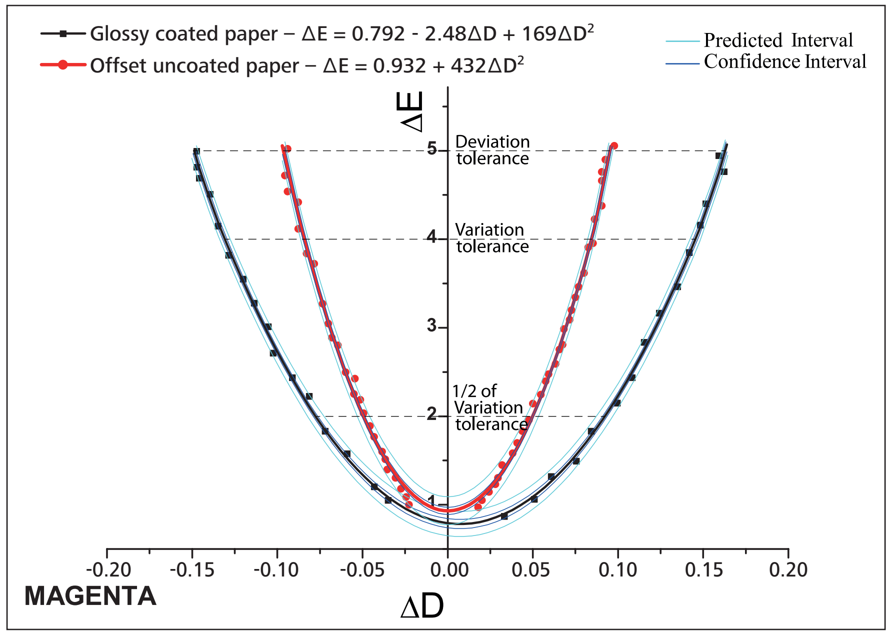

Figure 2: ΔD – ΔE function for Magenta

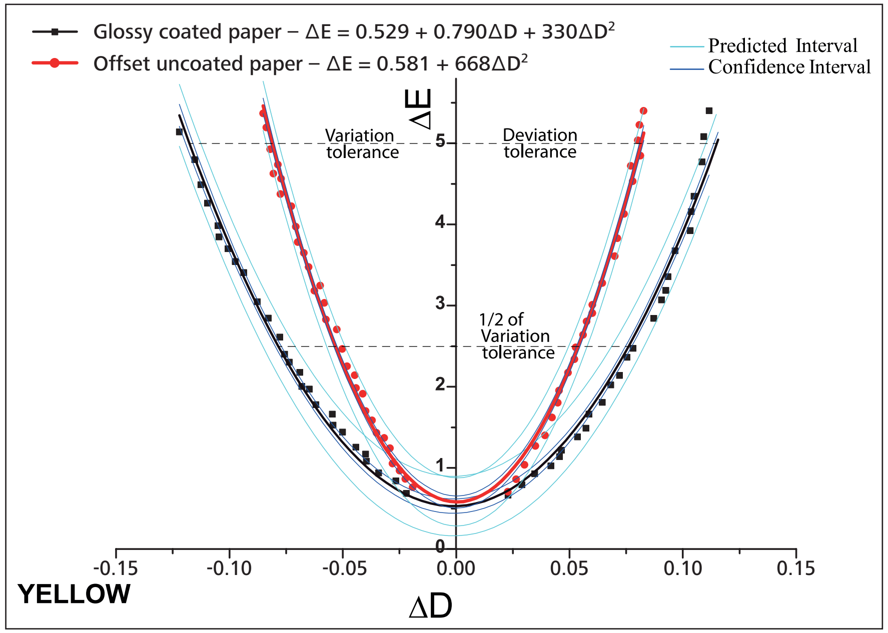

Figure 3: ΔD – ΔE function for Yellow

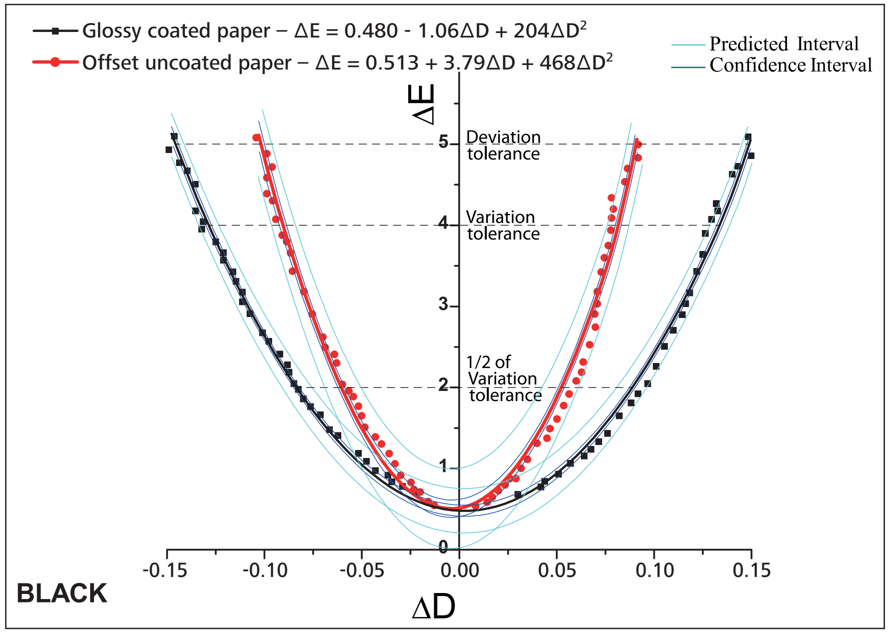

Figure 4: ΔD – ΔE function for Black

Q_R has degree of freedom $\nu_R = k - 1$, where k is the number of estimated parameters.
Q_{res} has degree of freedom $\nu_{res} = N - k$, where N is the number of observations. The degrees of freedom of Q_0 are $\nu_0 = \nu_R + \nu_{res}$. The dispersions of sums of Q_0 and Q_{res} are calculated with Formula 6:

$$s_R^2 = \frac{Q_R}{\nu_R} \quad \text{and} \quad s_{res}^2 = \frac{Q_{res}}{\nu_{res}} \qquad (6)$$

For improvement of analyses of experimental data, all output data from an analysis of variance study (ANOVA) are arranged in tables for each of obtained models. Lists the sources of variation, their degrees of freedom, the total sum of squares, and the mean squares can be seen at Table 3 below. The analysis of variance table also includes the F-statistics and p-values [14]. The usage for determine whether the predictors or factors are significantly related to the response.

Step B. Examination of the hypothesis for coefficient significance
The main goals of this examinations of the hypothesis for coefficient significance in this research was to check the possibility the value of some of coefficients to be different from zero, as result of minor number of observations or accident disturbance.
The examination is completed by Formula 7 by calculation of value, which has a Student distribution (Student's t-test for assessing the statistical significance). If the coefficient of matrix - cij are equal to zero [14, 16], then coefficients of regression model are significant.

$$t_i = \frac{|b_i|}{s\{b_i\}} = \frac{|b_i|}{s_\varepsilon \sqrt{\{c_{ij}\}}} \qquad (7)$$

where s_ε is assessment of root mean square deviation of accident disturbance. The parameter t_i has $\nu = n - 1$ degrees of freedom, when n is number of observations.

In the analyses of results was accepted level for α=0.05. For each of obtained experimental models have been checked the t-values from the tables with t-Student's data. If $t_i > t_{Table}(\alpha, \nu)$, then the coefficient is significant. If $t_i < t_{Table}(\alpha, \nu)$, then the coefficient is not significant and should be removed from the model.

Step C. Examination of the significance of determination coefficient - R²
Coefficient of significance - R^2 (Formula 8) defines the correlation between regressors and predicted value - $\hat{y}$.

$$R^2 = \frac{Q_R}{Q_0} = \frac{Q_0 - Q_{res}}{Q_0} = 1 - \frac{Q_{res}}{Q_0} \qquad (8)$$

It is very important to make examination of the significance of determination coefficient [15] - R^2. In this research, for examination of R^2 was calculated the value of Fisher's distribution coefficient F (Formula 9).

$$F = \frac{s_R^2}{s_{res}^2} = \frac{Q_R / \nu_R}{Q_{res} / \nu_{res}} = \frac{R^2 (N - k)}{(1 - R^2)(k - 1)} \qquad (9)$$

In the analyses of results was accepted level for α=0.05. Each of the obtained experimental models has been checked and compared with the $F_T = F(\alpha, \nu_R, \nu_{res})$ values from the tables with Fisher's distribution data.
If $F > F_T$, then the model and R^2 are adequate.
If $F \le F_T$ then the obtained model and R^2 are not adequate.

Step D. Examination of the adequacy hypothesis of regression model through repetitive trials
One of the most important examinations of the obtained mathematical models is the examination of the adequacy hypothesis of regression model through repetitive trials. Without that examination of the regression models, nobody can testify that the obtained models will have some practical implementation.

Table 3: Sample of ANOVA Table

Source	Sum of Squares	Degrees of Freedom	Dispersions	F-statistics
Regression Error (residual)	Q_R Q_{res}	ν_R ν_{res}	s_R^2 s_{res}^2	$F = \frac{s_R^2}{s_{res}^2}$
Total	Q_0	ν_0	-	-

By that reason, about two months after the main experiment described in this paper, in the same production conditions (same papers, inks, printing press, printing plates, etc.) the experiment was repeated. The same measurements have been made. The algorithm for examination was [15]:

- Defining the dispersion of the repetitive trial (Formula 10) where $y_{1d}, y_{2d}, \ldots, y_{nd}$ are the new obtained results from repetitive trials, $\bar{y}_d$ is the mean value of repetitive trials

$$s_{\varepsilon}^{2} = \frac{1}{n-1}\sum_{i=1}^{n}(y_{id} - \bar{y}_d)^2 \qquad (10)$$

- if $s_{res}^2 > s_{\varepsilon}^2$ then was calculated

$$F = \frac{s_{res}^2}{s_{\varepsilon}^2} \qquad (11)$$

The model is adequate if $F \le F(\alpha, \nu_{res}, \nu_{\varepsilon})$, when for α is accepted 0.05; $\nu_{res} = N - k$, $\nu_{\varepsilon} = n - 1$.

- if $s_{\varepsilon}^2 > s_{res}^2$ then was calculated

$$F = \frac{s_{\varepsilon}^2}{s_{res}^2} \qquad (12)$$

The model is adequate if $F \le F(\alpha, \nu_{\varepsilon}, \nu_{res})$, when for α is accepted 0.05; $\nu_{\varepsilon} = n - 1$, $\nu_{res} = N - k$.

All of the experimental data and regression models obtained by experimental data (Table 4) have passed through these four steps (step A, B, C and D). In addition, for better analyses of data, for each model were obtained the histogram for residuals, normal plot of residuals, residuals versus fits and residuals versus order [16].

Figures 1–4 represent the experimental data and the graphics of the regression models ΔEab=f(ΔD). In addition to the models obtained (in this case - parabola), the confidence and the predicted intervals are visualized also. The deviation and variation tolerances [4] from Table 3 are shown with dashed line on the Figures 1, 2, 3 and 4.

When the restrictions of ΔEab tolerances for each of process colours are implemented to regression models, by analytical approach have been determined the roots of equations for each of combinations ink colours – used paper. The obtained results are shown in Table 5 and Table 6.

Analyses of the achieved results for all eight obtained mathematical models shows:

1. For glossy coated and for uncoated papers, the coefficients for main ink colours are different, "a" have a biggest value for yellow, and lowest value for cyan (Figures 1–4). Therefore for yellow we have smaller limits, and for cyan more wide limits. Coefficient "b" shift the parabola [22, 23] for 5 of equations – ΔEab= f(ΔD) in right hand direction, and for three cases in left hand direction. Therefore for five cases the limits in plus (+) will be higher, and for three cases in negative (-).
2. The parabola in not one case does not cross in the same time zero point of abscise and ordinate. The values of the coefficient "c" are insignificant and smaller than 1 and that fact may be caused by non-uniformity of paper/ink/printing press properties, etc.
3. When we compare the main colours in the different type of papers we determine that the coefficient "a" is from 2 to 3 times bigger for the uncoated paper. Therefore for uncoated paper we have lowest limits [18, 19]. The reason is in optimal ink quantity for uncoated papers.

Table 4: Regression models ΔE=f(ΔD) obtained by experimental data for C, M, Y, K and two types of paper

Paper Type	**ΔE = aΔD² + bΔD + c (y = ax² + bx + c)**			
	Cyan	**Magenta**	**Yellow**	**Black**
Glossy coated	ΔE = 128 ΔD² + 4.38 ΔD + 0.766	ΔE = 169 ΔD² – 2.48ΔD + 0.792	ΔE = 330 ΔD² + 0.790 ΔD + 0.529	ΔE = 204 ΔD² – 1.06 ΔD +0.480
Offset uncoated	ΔE = 315 ΔD² – 1.96 ΔD + 0.813	ΔE = 432 ΔD² + 0.932	ΔE = 668 ΔD² + 0.581	ΔE = 468 ΔD² + 3.79 ΔD + 0.513

Table 5: Density difference limitations (deviation and variation tolerances) for plus (+) and minus (-) direction for glossy coated paper

	Tolerances for Glossy Coated Paper							
	Cyan		Magenta		Yellow		Black	
	- ΔD	**+ ΔD**	**- ΔD**	**+ ΔD**	**- ΔD**	**+ ΔD**	**- ΔD**	**+ ΔD**
Deviation Tolerances	-0.200	0.166	-0.151	0.165	-0.118	0.115	-0.146	0.151
Variation Tolerances	-0.177	0.143	-0.131	0.145	-0.118	0.115	-0.129	0.134
½ of Variation Tolerances	-0.117	0.083	-0.078	0.092	-0.078	0.076	-0.084	0.089

Table 6: Density difference limitations (deviation and variation tolerances) for plus (+) and minus (-) direction for uncoated paper

	Tolerances for Uncoated Paper							
	Cyan		Magenta		Yellow		Black	
	- ΔD	**+ ΔD**	**- ΔD**	**+ ΔD**	**- ΔD**	**+ ΔD**	**- ΔD**	**+ ΔD**
Deviation Tolerances	-0.112	0.118	-0.097	0.097	-0.081	0.081	-0.102	0.094
Variation Tolerances	-0.098	0.104	-0.084	0.084	-0.081	0.081	-0.090	0.082
½ of Variation Tolerances	-0.058	0.065	-0.050	0.050	-0.054	0.054	-0.061	0.052

4. Conclusions

For first time via experimental research in real production conditions, the deviation and variation tolerances from optimal inking density value were determined, taking into consideration the human optical perception and the specific production conditions – print substrate – ink – printing press. It is unallowable to use equal limits for deviations of optical density from optimal inking value for different types of paper and equal value limits for all 4 process colours.

The obtained results for deviation and variation tolerances can be used in practice for preparing for print for sheet-fed offset presses and for quality control of printing process. The limits for different types of paper, does not depend of used equipment. The methodology from this paper can be used in printinghouses for determinations of admissive tolerances for deviations and variations from OK print for specific printing conditions of any printing houses.

The coefficients obtained from the regression models are not equal for the different paper-ink combinations, which suppose different limits for ΔD.

The values of obtained for deviation and variation tolerances have a significant difference between different paper types and between different ink colors.

For most of the paper types and colors, deviations in different directions – positive or negative, were observed. From all eight developed models, six of them are characterized by different tolerances in positive or negative direction. The deviation tolerances' values for two models are similar.

5. Future researches

A research study and implementation of methodology from this research should be performed for the others major types of printing papers defined in ISO standards.

In future, by collected data from this research, it could be developed mathematical model describing relationship between ink quantity, colour differences from OK print and gamut volume changes. Certainly it will be very useful for predicting of correct colour reproduction in different inking quantity conditions.

6. References

[1] Kachin, N./Spiridonov, I. (2000): "Printing Processes, Part I. Theoretical Bases", Pleiada, Sofia.
[2] ISO 12647-1:2004, "Graphic technology - Process control for the production of half-tone colour separations, proof and production prints - Part 1: Parameters and measurement methods".
[3] Kipphan, H. (ed.) (2001): "Handbook of Print Media: Technologies and Production Methods", Springer, Heidelberg.
[4] ISO 12647-2:2004, "Graphic technology - Process control for the production of half-tone colour separations, proof and production prints - Part 2: Offset lithographic processes".
[5] ISO 13656, "Graphic technology - Application of reflection densitometry and colorimetry to process control or evaluation of prints and proofs".
[6] ISO 2846-1, "Graphic technology- Colour and transparency of ink sets for four-colour-printing".
[7] Seimour J. (2007): "How many dE are there in a dD?", Proc. TAGA – Technical Association of the Graphic Arts, 59-th Annual Meeting, Pittsburgh, USA.
[8] Viggiano, J.A./Wang, J. (1991): "A Suggested Method for Computing Colorimetric Densities", Proc. TAGA – Technical Association of the Graphic Arts.
[9] ISO 5-3:2009, "Photography and graphic technology - Density measurements - Part 3: Spectral conditions".
[10] ISO 5-1:2009, "Photography and graphic technology - Density measurements - Part 1: Geometry and functional notation".
[11] ISO 5-4:2009, "Photography and graphic technology - Density measurements - Part 4: Geometric conditions for reflection density".
[12] Kachin, N./Spiridonov, I. (2004): "Optical Density and Colour Difference in Printing on Different Types of Paper", Cellulose Chemistry and Technology, vol. 38 (3-4), 255-264.
[13] Vuchkov, I./Stoyanov, S. (1983): "Mathematical modeling and optimization of technological objects", Tehnika, Sofia.
[14] Tsochev, V./Damgaliev, D./Kozarev, N./Manolov, N. (1994): "Handbook of optimization methods for experimental researches", Martilen, Sofia.
[15] Vuchkov, I./Stoyanov, S./Tsochev, V./Kozarev, N. (2002): "Handbook of practical implementation of statistical methods", Novi znania, Sofia.
[16] Stoyanov, S. (1993): "Optimization of technological processes", Tehnika, Sofia.
[17] Kendall, M. (1957): "Rank Correlation Methods", London, Griffin.
[18] Korn, G./Korn, T. (2000): "Mathematical Handbook for Scientists and Engineers: Definitions, Theorems, and Formulas for Reference and Review", Dover edition.
[19] Angelov, V./Vitanov, T. (2011): "Reference book of Mathematics", Sofia, Anubis.

(received for the first time: 04-04-11)

Iskren Spiridonov

Dr.,
Department of Printing Arts, Pulp and Paper, University of Chemical Technology and Metallurgy, Sofia, Bulgaria

i_spiridonov@abv.bg