Study of Color Quality Uniformity in Digital Dry Toner Electro-photographic Printing

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***Abstract*—The value of digital printing today lies not only in replicating offset work on a smaller scale or at a shorter run length, but it lies in developing unique, high-value products. Also digital printing has made inroads in the packaging markets, where offset and flexography have been long dominant. Kodak NexPress2100 Plus is an example of digital dry toner electro-photographic computer-to-print system, targeted to short runs in commercial, publication, and even packaging environmental printing.**

In this paper we take a close look at the color capabilities of a current high-speed electro-photographic digital dry toner Kodak Nexpress2100 Plus printing machine. As a result we found a large color gamut for three different types of paper, reproducing pleasing color images with process CMYK dry toners. For assessing uniformity of the printed quality it is relevant to be compared different samples printed successively on the same paper and the same conditions. Printed tests by digital printing platform are included. Thus we are able to assess the printed results to form our analyses regarding color characteristics achieved.

Upon visual and quantitative analyses this paper concludes that digital Kodak Nexpress2100 Plus has shown the great advantage giving print service providers the ability to handle new and different applications.

***Index Terms*—color quality, digital printing, electro-photography uniformity**

I. INTRODUCTION

Digital printing has helped print service providers better cope with a changing print market. Nowadays the printing technology users and providers, expect rapid improvement of digital printing devices. The value of digital printing lies especially in developing specific, high-value products and applications. Not just any high value products and applications, but those that are in demand in a constantly and rapidly changing marketplace. New substrates, new inks, new finishing options, and new ways of ensuring high-quality imagery are having an impact on what is being demanded by the market. At the same time, being able to profitably produce these applications is of paramount importance. [1]

The great advantage of digital printing is possibilities to change printing information cycle by cycle of process and to print variable and personal data of information. Electro-photography is one of so called digital, non-impact printing technologies. It is master-less dynamic technology where there is not permanent intermediate carrier of information. Generally Electro-photography (EP) with dry toners is a digital printing method, based on the electrostatic toner transfer on the printed substrates.[2]

Electro-photography is not only the oldest, but also the most complex digital printing technology, consisting of two critical materials (the toner and the photoconductor/photoreceptor) and seven process steps (charge, expose, development, transfer, fuse, clean and erase). [3] The principal advantages of Electro-photography, over other non-impact printing or digital printing technologies, are:

- Excellent print quality for text, graphics, and pictorials
- Large speed range.

On every cycle the information is exposed (by laser or LED) on the organic photoreceptor forming latent image. Then due to the toner transfer, image can be visual. Toner particles with different polarity are charged and then they adhere on the cylinder, developing the image. The important factor that can affect electro-photography is humidity. Toner tends to charge to a higher level in dry environment and a lower level in moist air.[3]

Today are used predominantly two-components toners – pigment + carrier. The color electro-photographic process is more sensitive to toner particle size range. Toner is a very fine powder. The design and maintenance of the shape of the toner particles and the relative distribution of larger and smaller particles in the EP system is a critical design factor that has significant effects on print quality. The particles are made from a liquid in what is a direct chemical polymerization process produced a narrower range of particle sizes and shapes than can be obtained from the grinding process. [3]

In the end the toner is transferring on the substrate through electrostatic power (corona) and set up on it by fusing and fixing through heating and pressure. Therefore, for each cycle as we have not permanent carrier of information (printing plate), we may have probably different image printed quality. This is the key factor in this digital printing method, defined the quality repeatability and uniformity of the whole printed outputs. The print quality also is affected by the particle size of toner, its geometric form and chemical/physical structure. [4]

Systems such as the Kodak Nexpress platform is one example which allows printers to offer high-value products and applications that removed from the traditional print jobs they have been used to. The advantage to the Nexpress is that it gives print service providers the ability to nimbly handle new and different usage which is their better respond to

Manuscript received September 12, 2014.

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changes in the market, and thus better serve the needs of customers. [1]

In this article we take a close look at the tone and color capabilities of one of the high-speed electro-photographic dry toner digital press - *Kodak Nexpress2100 Plus*, which has the great advantage giving print service providers the ability to handle new and different applications. That is why we look specifically at the Kodak Nexpress2100 plus platform, at its features and functions, and how it can enable the commercial print provider to exploit these high-value print applications.

Kodak NexPress2100 Plus is a 5-coloured single-pass system, comprises of successive five imaging and printing units for each process color (CMYK+1). To print a multicolor image, the printing sheet passes through five printing units to receive toner and this happens in one pass. Each color section transfers the color image to the paper in sequence until the entire image is on the paper. This single pass architecture transfers the color images onto an intermediate drum and then transfers the complete image onto paper before fusing. The imaging speed corresponds to the printing speed.[5]

The Kodak Nexpress2100 Plus is a highly versatile digital press providing the best all-runs performance. This press is able to provide standard CMYK finish and Clear Dry Ink outputs.

In our research we found out that the Kodak Nexpress2100 Plus has a very satisfied color reproduction capability, like color gamut, color deviation, tonal value increase, optical densities, keeping reliably constant uniform printing quality during the whole printing process. It can not only reproduce pleasing color images with legacy CMYK files, but also can be color-managed to match even offset quality. [6][7]

The printed results are assessed differently, including visually and quantitative analyses, in order to form our opinion regarding image quality. Upon these analyses, the report includes objective parameters, characteristics the print quality of dry toner electro-photographic Nexpress2100 Plus.

II. EXPERIMENTAL

The objective of the paper experimental is to examine image quality of Kodak Nexpress2100 Plus. In particular, our purpose is to find out how this press can print pleasing stable color images from legacy CMYK files and how can keep uniformity of color quality print by print. Key elements of our experimental work include calibrating the printing system, designing test forms containing CMYK images and color-managed pictorial images, performing quantitative and visual analyses.

For this purpose have been used test files as a characterization target for device profiling and for quantitative analysis. Test files were printed on the Kodak Nexpress2100 Plus, using frequency-modulated screening with 20 μm of dot. ICC device link technology is used to convert pictorial color reference images from the FOGRA color space to the Kodak EP press's color space. [8]

In two test forms (Fig.1, Fig.2) there are several elements to be measured - scale *IT8.7-3 Visual*, single, double and three inks coverage patches, gray balance, gradation patches for different process colors, positive and negative lines under 0° and 45° for small details. In the *Test-form 2* there are also color images for very easy visual color deviation assessment. Test-forms are generated by the help of Test Chart Generator, part of the Profile Maker software.

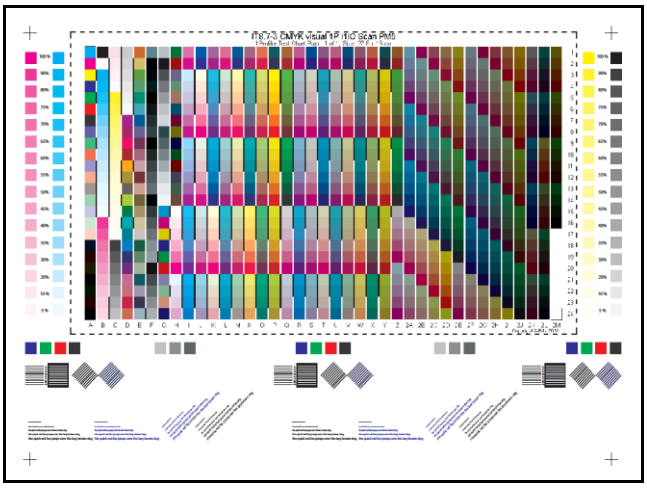

Fig. 1 Test chart IT8.7-3 Visual

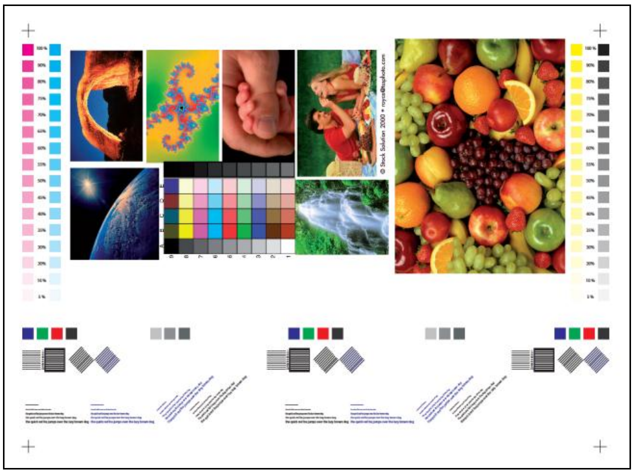

Fig.2 Test-form for visual color assessment

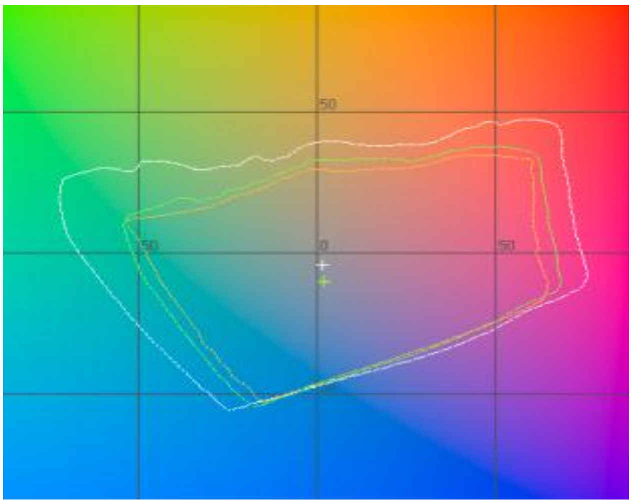

Fig. 3 Color gamut of printed papers type, Kodak Nexpress2100 plus

Two test-forms are printed on the high quality paper type - wood free coated (WFC) glossy, three different grades: paper 1 – 90 g/m^2, paper 2 - 130 g/m^2 and paper 3 - 200 g/m^2.

After printing the results of data characterization IT8.7-3 visual are scanned and measured separately for every three kind of papers in standard lightening D50. All colorimetric measurements are done using an X-Rite i1iO with i1Profiler spectrophotometer. From the received data had to be generated color gamut for each grades of papers. (Fig.3)

Measurement data will be acquired using i1Profiler and Profile Maker 5.0.5b. In order to compare different color gamut, we have: yellow line – paper 1, green line – paper 2, and white line – paper 3. (Fig.3)

On the other hand, to be assess uniformity of the printed quality it is relevant to be compared different samples printed successively on the same paper and the same conditions: we take paper 3 (WFC, glossy, 200 g/m^2, sample 1 – one sided print and other three double-sided samples - 2, 3 and 4.

For these printed samples we have measured: color gamut through test-scale IT8.7-3 Visual, and then we have compared different samples on the base of color deviation ΔE_{94}. For differentiation the color gamut we have: sample 1- white line, sample 2- red line, sample 3- green line and sample 4 – orange line. (Fig.4)

Color deviation (ΔE) is traditional criteria for definition uniformity between successive printouts. In our case ΔE is calculated according the equation 1994. This is a "weighted" Delta E equation that provides better correlation between measured and perceived color differences. The results is based exclusively on ΔE*94 unless otherwise stated.

$$\Delta E^{*}94 = [(\Delta L^{*}/kL.SL)^2 + (\Delta C^{*}_{ab}/k_{C}.S_{C})^2 + (\Delta H^{*}_{ab}/k_H S_H)^2]^{1/2}$$

where,

$S_L=1$; $S_C= 1+0{,}045C^{*}_{ab}$; $S_H=1+0{,}015C^{*}_{ab}$

$K_L=K_C=K_H=1$

Evaluation is made according FOGRA and ISO ΔE tolerances in. [9]

Table I. Evaluation according the color deviation

ΔE values	Assessment
0 - 1	Unnoticeable difference
1 - 2	Very little difference (for trained eye)
2 – 3,5	Middle difference, noticeable for untrained eye
3,5 - 5	Noticeable difference
>6	Unacceptable, very strong difference

In the practice there are different formulae for color deviation definition and this is a reason for receiving different correlation with visual color perception. That is why for more compatibility we choose method from 1994 where colors matches is above 95%. These calculations are on the base of such color attributes as L-lightness, C – saturation and H- hue. (The connection between L*a*b* color coordinates and those of LCH is: $C= (a^2 +b^2)^{1/2}$ and H_{ab}= arctg a*/b*). [4]

Color deviation ΔE is calculated automatically on the base of IT8.7-3 Visual scale measurement.

Except color gamut and color deviation for our purpose have been measured also such important color reproduction quality parameters as: dot gain and solid inks densities.

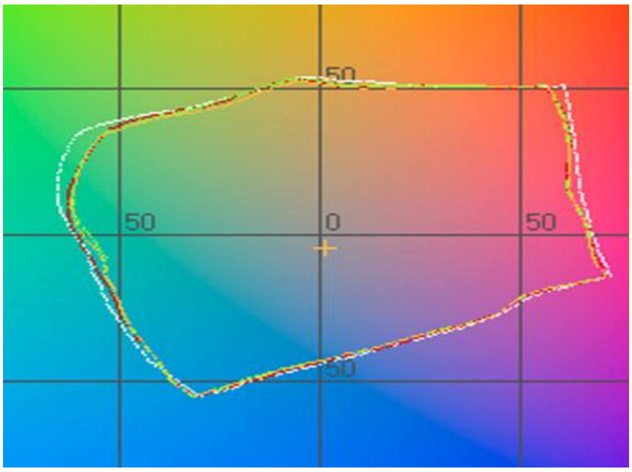

Fig.4 Color gamut of successive samples printed on WFC glossy paper, 200 g/m^2

III. RESULTS AND DISCUSION

There are two aspects of color image assessment - colorimetric measure of characterization data sets, and visual comparison of the picture color images. It is important that findings from one analysis support the other. Colorimetric targets are based on measurement data generated per ISO 12647. [9],[10]

On the base of the results (Fig. 3) can be concluded that paper number 3 (200 g/m^2) has a largest color gamut, then paper 2 (130 g/m^2) and in the end - paper 1(90 g/m^2). It is clearly seen that paper types 3 have the largest color gamut on the higher values of L. In the experimental we have found that the same range have kept on the other value of lightness (L) but the color gamut become smaller – paper 3, paper 2 and paper 1. Only in the blue-violet area paper 1 and paper 2 have the same gamut as paper 3. The more reproducible colors are in the high positive values (>25) of the CIE a*b*. In the same time the part of the colors are in the area of the negative values of the coordinates. But the relevant conclusion from Fig.3 is that the biggest color gamut is for paper 3 – WFC, glossy, grade 200 g/m^2, what means that on this substrate can be reproduced more saturated color compared to other kinds of papers. That is why next research we have done on this paper (number 3). Paper 1 and paper 2 have almost the same color gamut which allows they can be substitute in different color applications.

On the base of the results shown on Fig. 4 can be concluded the color gamut of different successive samples, printed on the chosen type of paper - WFC glossy paper, 200 g/m^2, are almost overlapped, which is an indicator that all printouts are equivalent by their color reproduction quality. There are very insignificant differences which are not important for receiving repeatable print quality.

Furthermore from the Fig.4 can be seen that for all double sided printouts the difference is not noticeable at all. All three successive double-sided samples have almost the same color gamut. But the difference is between one sided sample 1 and other three double-sided samples - 2, 3 and 4.There is a little difference only in the blue-green area, what is not essential. Conclusion is that samples of this wood free coated glossy paper, 200 gsm, reproduce repeatable, very satisfied colors of all area and this results prove the Nexpress2100 Plus color reproduction capability is very acceptable.

Analyses of the color deviation calculated as ΔE_{94} of the successive double sided samples (WFC *paper 200 g/m^2 – double-sided samples 2, 3 and 4)*, where the main color characteristics are hue and saturation (LCH), have shown the following:

Average color deviation is minimal between samples 2 and 3, e. g. the color perception of these printouts are almost equal. (Table II) More distinctive deviation exists between samples 3 and 4, but here also the average ΔE is less of one (0,84) and therefore the deviation is also not so essential. (Table IV)

On the whole the average ΔE for these three double-sided samples is less of one, what is very good result. The max color deviation (ΔE_{max}) from all measured patches is between samples 2 and 4 - ΔE=3,78. (Table III) But if ignore 10% of all fields with max color deviation, the rest 90% of all fields the max ΔE is 1,30, what is very little difference according tolerances, shown in Table I.

Table II. Color deviation (ΔE_{94}) for samples 2/3

Fields /ΔE	Average ΔE		Standard ΔE		Max ΔE	
	Meas u red	Numbe r of fields	Measu red	Numbe r of fields	Meas u red	Numbe r of fields
All fields	0,68	928	0,39	928	2,97	928
90% of lowest	0,59	835	0,27	835	1,16	835
10% of highest	1,49	93	0,32	93		

Table III. Color deviation (ΔE_{94}) for samples 2/4

Fields /ΔE	Average ΔE		Standard ΔE		Max ΔE	
	Meas u red	Numbe r of fields	Meas u red	Numbe r of fields	Meas u red	Numbe r of fields
All fields	0,73	928	0,47	928	3,78	928
90% of lowest	0,62	835	0,31	835	1,30	835
10% of highes t	1,75	93	0,49	93		

All results have shown that paper samples printed by digital dry toner EP Nexpress2100 Plus, have constant, reliable and repeatable color reproduction quality, regardless of the fact that permanent carrier of images here is missed.

Table IV. Color deviation (ΔE_{94}) for samples 3/4

Field s /ΔE	Average ΔE		Standard ΔE		Max ΔE	
	Meas u red	Numbe r of fields	Meas u red	Numbe r of fields	Meas u red	Numbe r of fields
All fields	0,84	928	0,48	928	3,39	928
90% of lowest	0,72	835	0,33	835	1,44	835
10% of highest	1,86	93	0,46	93		

Most of analyses have shown that between our double sided samples there is unessential color difference and thus satisfied color reproduction quality. These results are acceptable for describing good uniformity of production printed by digital dry toner Nexpress2100 Plus.

Another parameter describing halftone printed color quality is *Dot gain*. The results of measured samples printed on most acceptable paper (paper WFC, glossy, 200 g/m^2) can be seen in Table V.

Table V. Dot Gain for WFC glossy paper, 200 g/m^2

Tone value	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %
	Dot Gain [%]								
C	7	15	19	21	24	23	18	15	8
M	7	14	18	20	22	22	18	14	7
Y	5	12	19	23	24	23	20	14	8
K	8	16	21	23	23	22	18	15	8

The visual comparison of tonal value increase for all CMYK colors is presented on the Fig.5. The tonal value increase is different for all CMYK colors. What is common for all 4-colored printed samples is the equal dot gain for the very darkness.(Fig. 5) In this printed area since 80% to 90% the tonal values increase are identical. In the areas of very lightness (10%) dot gain is almost the same except of yellow color. But there is a definite trend for this parameter in the middle tones (40- 60%) – max values for all process color.

From data on the Table V and Fig. 5 have seen that for yellow and cyan the values of max dot gain is higher than those for magenta while for black max values of dot gain comprises large tonal interval – since 30 to 60%. In the lightness and the very darkness comparison of the dot gain values have shown some compatibility between all CMYK process colors.

The main conclusion is all values are changed in very narrow interval what is shown stability of reproducible test forms during the whole printing process.

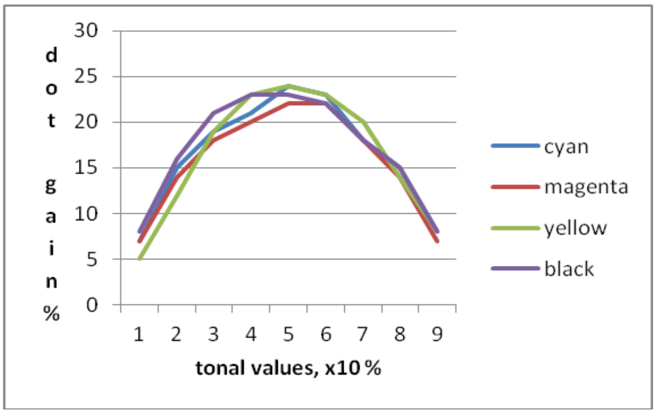

Fig. 5 Comparison of dot gain for CMYK colors

Towards *solid inks densities (SID)* can be said that here are observed more deviation between different printed samples of process colors. (Fig.6) For Black and magenta values are higher and more stable when for cyan measured values are very different. For yellow solid ink densities are almost equal, but lowest than others as the absolute values. For magenta optical densities for solids are higher compared to other process inks while the variation of values for cyan is most distinctive what may be explained by some mistake in measurement.

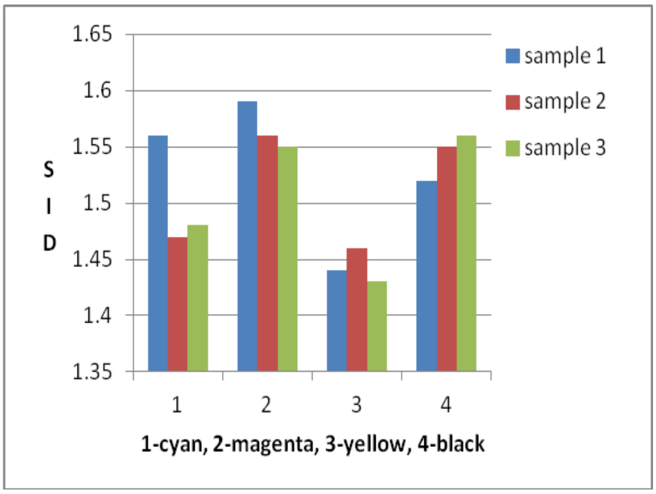

Fig.6 Variations of solid ink densities (SID) for CMYK colors

Achievable optical densities values and their variation between each other can be explained by toner quality particles and by specific process feature like fusing and fixing in the end of electro-photographic printing.

But nonetheless of all variation of densities, the measured values are corresponded to standard tolerances what is very satisfied and make sure that color density prints correctly.

The whole color reproduction results received of this digital dry toner EP printing platform have demonstrated the potential of approaching offset print quality. This can be proved by interpreting some parameters in relation to a sheet-fed smart dry offset Heidelberg Quick-master DI-46 press. [6]

CONCLUSION

Upon the results and analysis of this study it was found that the Kodak Nexpress2100 plus system produces stable and pleasing color print quality. The image quality of digital color output matches the standard criteria and enables high-value application.

This digital dry toner electro-photographic system enables significant gains in image quality, productivity and growth for print jobs, due to the platform's flexibility. Conclusion is having the Kodak Nexpress2100 plus platform makes it an attractive option for print service providers.

Nowadays the digital electro-photography printing technology is a high positioned printing method, taking advantage of improved print quality achieving even offset print quality for different printing products. As the quality of digital printing is increased, this is refers to as high-value applications. So can be said digital printing already is on the way for reaching a level of marketplace maturity. While digital printing has reached this level, there is still a significant amount of innovation occurring in the space, both from the perspective of technologies and the way to meet existing and emerging client needs.

Digital EP printing was one of those impulses in the information and communication sector which provided a positive impact at the whole digital printing and at the whole graphic arts industry.

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