IMPACT OF PRINTING ADDITIONAL INKS ON MULTICOLOR REPRODUCTION IN LIQUID TONER ELECTROPHOTOGRAPHY

UTJECAJ TISKA DODATNIH BOJILA NA KOLORNU REPRODUKCIJU U TEHNICI ELEKTROFOTOGRAFIJE TEKUĆIM TONEROM

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Abstract
In terms of increasing quality of reproduction there is sometimes a need to print additional spot inks together with the standard CMYK inks. One of the digital printing techniques that can achieve that is the liquid toner electrophotography. Modern printing machines that work on the principle of liquid toner electrophotography include an additional spot ink printing option. In this paper the impact of additional spot colour printing on a 4-colored reproduction will be analyzed, and by using spectrophotometric test a possible increase in quality will be defined. It is necessary to define how additional spot colours affect the reproduction of full tones, screening surfaces (CIEΔE, gamut reproduction) and how the printing substrate affects the final reproduction.

Key words: electrophotography, Hi-Fi printing, IndiChrome printing, spot inks, gamut of reproduction

Sažetak
U smislu povećanja kvalitete reprodukcije ponekad postoji i potreba za otiskivanjem dodatnih spotnih bojila uz standardna CMYK bojila. Jedna od digitalnih tehnika tiska koja može to postići je elektrofotografija tekućim tonerom, tzv. Digitalni kolorni ofset. Suvremeni strojevi koji rade na principu elektrofotografije tekućim tonerom uključuju opciju tiska dodatnih spotnih bojila. U ovom radu biti će analiziran utjecaj otiskivanja dodatnih boja na kolornu reprodukciju, te će se spektrofotometrijskim ispitivanjem definirati eventualni porast kvalitete. Pri tome je potrebno definirati kako dodatne boje utječu na reprodukciju punih tonova i rastriranih površina (CIEΔE, gamut reprodukcije), te kako na razliku u reprodukciji utječe sama tiskovna podloga.

Ključne riječi: elektrofotografija, Hi-Fi tisak, IndiChrome tisak, spotna bojila, gamut reprodukcije

1. INTRODUCTION

Well and faithfully transmitted information in printing technology today is enabled also with digital printing techniques. Digital printing is suitable for personalized and on-demand printed editions, which may account practically one print. In some digital printing techniques, because more simplified technologically solutions of varnishing and High Fidelity (Hi-Fi) printing is possible to increase the quality of printed products at minimum costs. While the Hi-Fi printing is rarely used in conventional printing techniques, it gets a sense with the common digital printing techniques (Inkjet and electrophotography).
The aim of this work is to determine the possibilities of additional ink printing options in liquid toner electrophotography technique (optional IndiChrome option), and detect possible higher quality than the standard CMYK printing option. It is important to define the change in quality incurred by additional ink printing and how on that affects the printing substrate. This will facilitate the customer's decision whether something will be printed with four color standard printing or optional Hi-Fi printing option.

2. THEORETICAL PART

2.1. Digital colour offset

Electrophotographic printing with liquid toner is rarer than electrophotographic printing with powder toners. In terms of print quality it is much higher than the powder toner and that can be attributed to the small particle size of the toner, which when applied to the printing surface is most similar to offset printing. [1]
With HP Indigo electrophotographic systems such pigment dye is called ElektroInk. ElektroInk particles (size 1μm) are electrically charged in the liquid and as such, they can be better controlled compared to the toner powder particles (size 6-12μm). As can be seen from Fig. 1, the toner powder particles should not be too small because then they become too light, and as such can create undesirable colored cloud. [2]

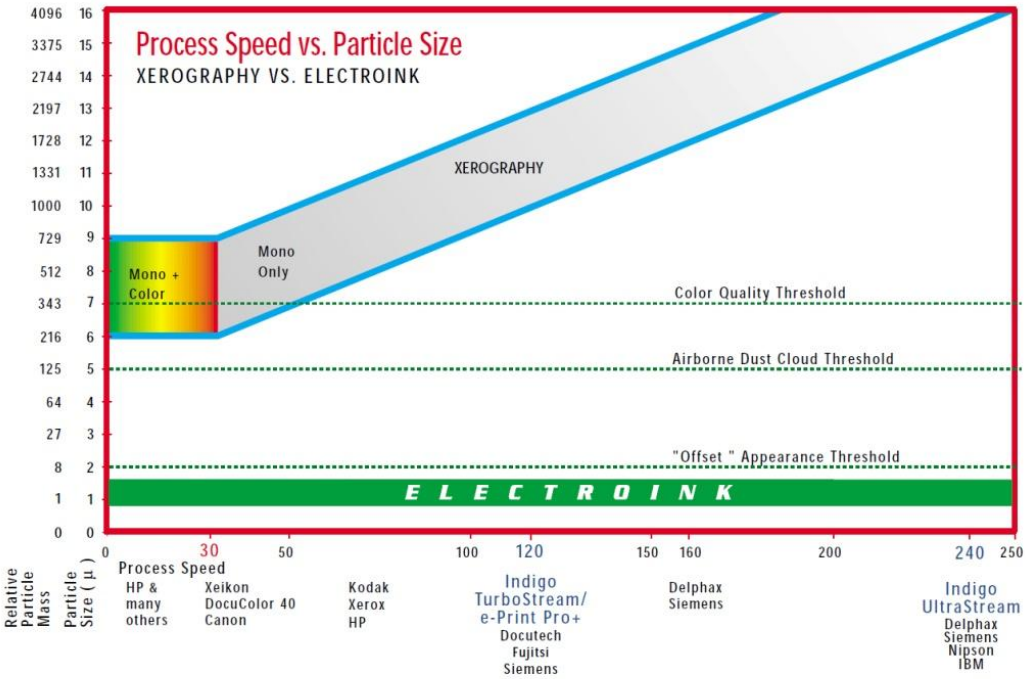

Figure 1. Ratio between the speed of printing and the particle size

HP Indigo printing systems uses special rubber blanket that is heated to a temperature of about 100°C. In contact with printing substrate the hot ink is fixed onto the cold printing surface and gives instant dry print, which is a big advantage over a printing technique in which the additional drying process are required. Printing is done by applying all color separations from the same print unit in order from the brightest to the darkest, which is possible since the ink is completely transferred to the printing surface from rubber blanket.[2]

In HP Indigo systems applying of more inks is resolved with satellite construction of the machine where the Binary Ink Developers (BID) are positioned above photoconductor drum, and they are active during the application of inks. In that way solved stamping machine construction provides printing with a greater number of separations, Hi-Fi printing puts in front and it becomes widely available. [3]

2.2. Hi-Fi printing

Hi-Fi printing is defined as a technology that by using additional ink raises fidelity of reproduction above the limitations of standard CMYK printing. There are implicit changes and additions to the standard CMYK printing, which then allows a wider range of printing color saturation and better reproduction accuracy.

Benefits of Hi-Fi printing are accepted by the designers (the ability to get more vivid and truer colors). It is particularly important in packaging printing (especially luxury), high-quality printing products and protective press.[4]

In conventional printing Hi-Fi printing is rarely used because of the higher cost of the final product. Higher costs are a result of the need for machines with more printing units, a large number of printing forms, additional time for machine setup and therefore the greater

press time. For the implementation of Hi-Fi press there are two printing methods available. One method is the use of bright CMYK colors (LcLmLyLk) besides standard CMYK colors to achieve a smooth transition and improve image detail from light to dark tones. In other way it is possible to achieve greater reproduction quality by using highly pigmented inks.[11]
Another method involves the use of different tones of color next to the standard CMYK colors.[5-10]
During the transformation of natural color in the RGB color space, and further to the CMYK color space there is some reduction in color gamut. Idea of HI-Fi printing is to broaden gamut of prints that they become close as possible to the gamut of colors in nature. Reproduction of highly saturated tones like shades of orange, purple, some red, blue, purple and some green cannot be achieved by standard CMYK printing method.[6]

2.3. IndiChrome printing

IndiChrome is protected name by HP (Hewlett-Packard) for their Hi-Fi printing where by using additional spot inks and bright inks together with default colors (CMYK) scores wider color gamut. HP IndiChrome system is possible only with the HP digital color offset technology with a unique ElectroInk ink. With HP IndiChrome technology it is possible to print smaller number of copies with special inks, create own colors and thereby increase the quality of reproduction in relation to the standard CMYK printing.
HP IndiChrome onPress is printing process where two spot inks (orange and purple) are added to the standard CMYK inks and all tones mixes from these six basic inks. This improvement can be achieved in the reproduction of those tonalities that match the used additional inks which is usually difficult to achieve with standard CMYK printing.[7]
HP IndiChrome Plus process with whom it is possible to achieve even greater improvements in the reproduction of tones with using additional green ink (CMYK + OVG).[7]
HP IndiChrome offPress process uses pre-mixed inks outside the machine. Inks are mixed from CMYK + OVG + reflex blue, intense yellow, rhodamine red and transparent white. After mixing, pigments are stored in containers and applied in additional press unit in the machine.[7]
HP ElectroInk special inks, fluorescent yellow and fluorescent pink ink, light cyan and light magenta, white ink and matt varnish enriches prints. HP ElectroInk light cyan and magenta inks allow photorealistic reproduction with smooth tonal gradations.[8]
Usage of bright colors is significantly reduced visibility of the screen elements and reduced graininess.[9]

3. EXPERIMENTAL

Additional printing of spot inks Orange (O) and Violet (V) has been experimentally investigated and their impact on the reproduction quality has been analyzed. The prints are printed on electrophotographic printing machine HP Indigo 5500. By spectrophotometric measurement it is determined a color difference between the prints obtained by standard printing (CMYK) and Hi-Fi printing (CMYK + OV). Spectrophotometers that are used for experimental measurements are X-Rite DTP 41 and X-Rite DTP 20 Pulse. Samples were printed on two commonly used paper substrates, glossy fine art paper: Magno Star Gloss 135g/m2 and uncoated paper Maxio set 140g/m2 from Sappi (Tab. 1. and 2.).

Table 1. Characteristic of the glossy fine art paper: Magno Star Gloss 135g/m^2

Parameter	Standard	Unit	Value	Tolerances
Basis Weight	ISO 536	g/m2	135	+/-4%
Thickness	ISO 534	mm	0,098	+/-8%
Opacity	ISO 2471	%	95	-1
Rel. Humidity	Tappi 502	%	50	+/-5
pH Value	ISO 6588	-	>7	-
Spec. Volume	ISO 534	cm3/g	0,70	+/-6%

Table 2. Characteristic of the uncoated paper: Maxio set 140g/m^2

Parameter	Standard	Unit	Value	Tolerances
Basis Weight	ISO 536	g/m2	140	+/-4%
Thickness	ISO 534	mm	1,002	+/-8%
Opacity	ISO 2471	%	95	-1
Rel. Humidity	Tappi 502	%	50	+/-5
pH Value	ISO 6588	-	>7	-
Spec. Volume	ISO 534	cm3/g	0,84	+/-6%

3.1. Work methodology

For the analysis of the gamut volume (ΔV) and graphical diagram, there are made ICC profiles for each sample, by computer program Monaco Profiler Platinum 4.8. In the same computer program has been made gamut sections, while gamut models are obtained from CHROMIX Colorthink Pro 3.0 computer program. For the analysis of characteristic tones, characteristic tone value and visual evaluation of CIE L*a*b* ΔE*, ΔL*, ΔC*, ΔH*, the computer program Color Shop X has been used. For graphical display is used a computer program Origin Pro 8.0., and the results are presented in CIE L*a*b* diagrams.

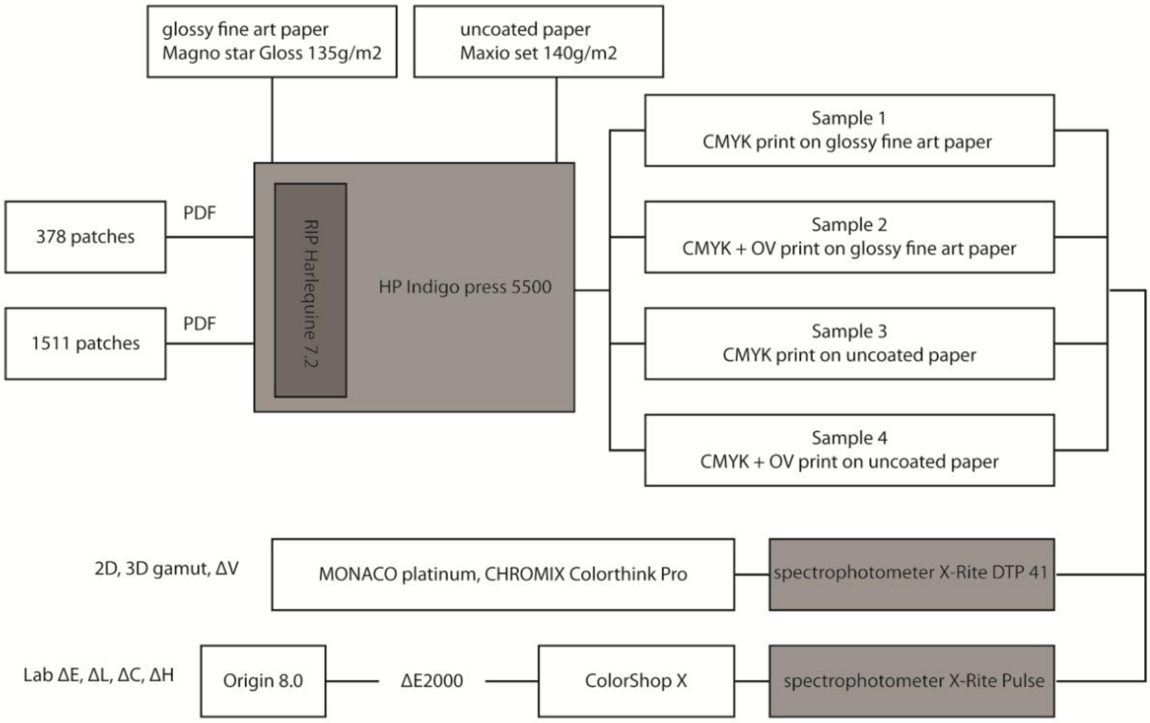

Figure 2.: Work methodology

4. RESULTS AND DISCUSSION

4.1. Gamut analysis

Gamut tells us directly about the quality of reproduction, which means, if the volume of gamut space is bigger, its better reproduction of tones. What will change in color vision cause by printing 6-colors (CMYK + OV) compared to the 4-color (CMYK) is shown in Fig. 3. and 4. In this comparison mathematically is calculated the difference in gamut volume (ΔV). In general, the prints that will be printed with additional inks (O and V) will have greater gamut volume.

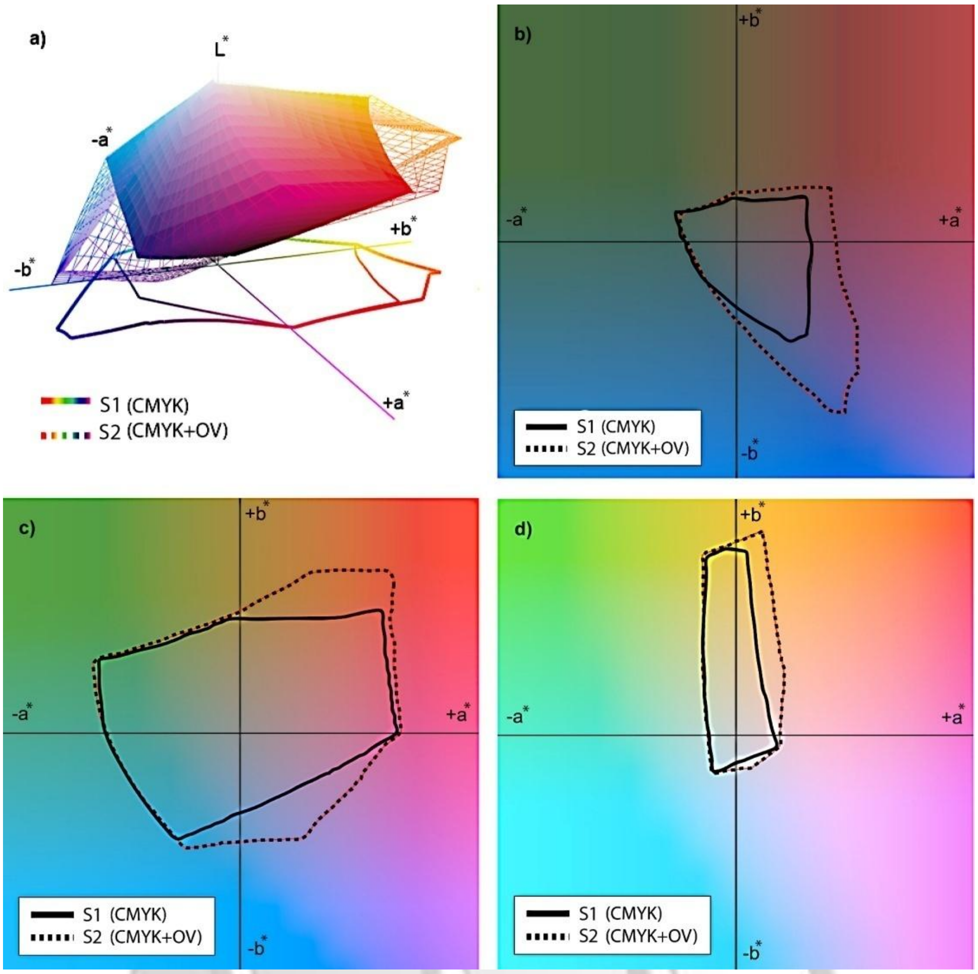

Figure 3. Display of gamut models on glossy fine art paper (Magno star Gloss), a) 3D construction, b) gamut section L20 c) gamut section L50, d) gamut section L80

On glossy fine art paper standard way of printing (CMYK) deliver the gamut volume V_{S1}=799,027, while with printing of additional inks (CMYK+OV) gamut volume is V_{S2}=1,145,849. It is made a big difference in the volume (ΔV=346,822) which means that sample 2 has a much higher color saturation. In the characteristic gamut sections is evident that in the darker tonal range sample 2 printed with additional inks (CMYK+OV) has a much higher color saturation from sample 1 printed by standard printing method (CMYK). Greater color saturation is particularly visible in blue, magenta, red and orange area. This kind of fluctuation in the results it is possible by theoretical total ink limit layer of 600%, which gives much more intense darker tones.

At the middle tone areas it shows the significant difference in the yellow, orange and red areas. Also the higher values are present in blue and magenta areas. Of course this was expected due to the additions of orange and purple pigments. In the brightest tonal range effect is the same, and there are also similar color changes that are visible in the yellow and the red areas.

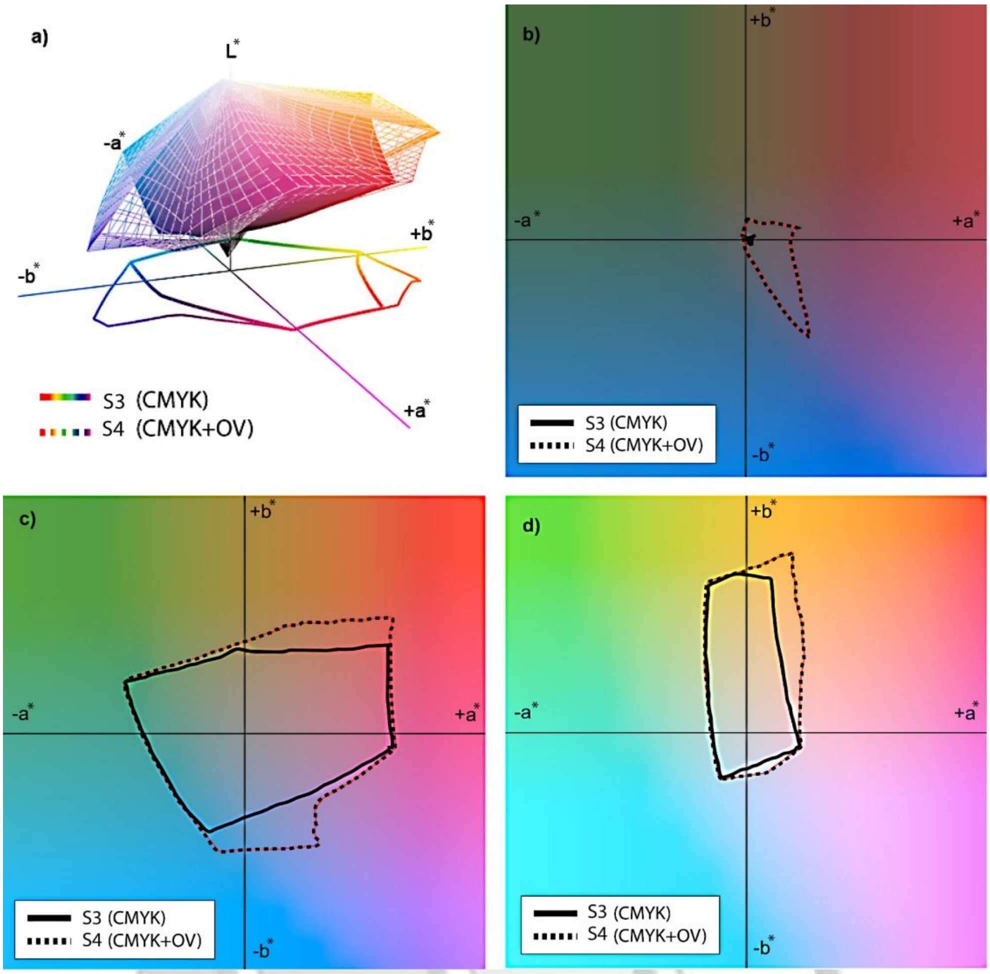

Figure 4. Display of gamut models on uncoated paper (Maxio set), a) 3D construction, b) gamut section L20 c) gamut section L50, d) gamut section L80

On uncoated paper, by standard way of printing (CMYK) it is constructed the gamut volume V_{S3}=557,224, while with additional inks (CMYK+OV) gamut volume is V_{S4}=775,361. By comparing these prints it is obtained difference in the volume of ΔV=218,137 which indicating that sample 4 has more saturated colors then sample 3. The fluctuation of results is similar as results of glossy fine art paper, but less intensely.

By analyzing the impact of the printing substrate can be concluded that it significantly affects the quality of the reproduction. By comparing the samples printed in standard way (sample 1 and sample 3) it is evident that the paper substrate which has a coating on it, will achieve higher gamut volume then uncoated substrate, where the difference in volume is: ΔV_{S1-S3} = 241,803. By comparing the samples printed in IndiChrome technique (sample 2 and sample 4) the difference in volume is: ΔV_{S2-S4} = 370,488. It is recommended to print additional inks on the smoother and coated printing substrates in order that improvement of the quality come more to the fore.

4.2. Analysis of characteristic tones and tone values

Gamut volume provides general information about reproduction where volume describes mainly reproduction of saturated tones (edge of gamut), but unfortunately does not give information on reproduction of tone values. Based on the measured CIE L*a*b* values (Fig. 5. and 6.) it was calculated ΔE^*_{00} color changes, the difference in lightness (ΔL^*), the difference in chroma (ΔC^*) and difference in hue (ΔH^*) for the characteristic tones. It is used an equation for calculating the differences in color ΔE^*_{00}, as follows:

$$\Delta E^*_{00}=\sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2+\left(\frac{\Delta C'}{k_C S_C}\right)^2+\left(\frac{\Delta H'}{k_H S_H}\right)^2+R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \quad (1)$$

Where ΔE^* is a colour difference, ΔL^* light difference, ΔC^* chroma difference, ΔH^* hue difference and k_L, k_C, k_H are parametric weighting factors. Other parameters S_L, S_C, S_H, T, R_C, R_T are defined as follows:

$$S_L=\frac{1+0.15(L'-50)^2}{\sqrt{20+(L'-50)^2}} \quad (2)$$

$$S_C=1+0.045C' \quad (3)$$

$$S_H=1+0.015C'T \quad (4)$$

$$T=1-0.17\cos(h'-30°)+0.25\cos(2h')+0.32\cos(3h'+6°)-0.20\cos(4h'-63°) \quad (5)$$

$$R_C=2\sqrt{\frac{C'^7}{C'^7+25^7}} \quad (6)$$

$$R_T=\sin(2\Delta\theta)Rc \; \Delta\theta=60\cdot\exp\left\{-\left[\left(h'_m-275°\right)/25°\right]^2\right\} \quad (7)$$

$$\Delta\theta=30\exp\left\{-\left[\left(h'-275°\right)/25°\right]^2\right\} \quad (8)$$

The visual estimate which is carried out by the average viewer, the difference in color ΔE^* can be grouped in five groups: difference until 1 is imperceptible to the human eye, from 1 to 2 it is very small color difference, from 2 to 3.5 the difference is moderate, from the 3.5 to 5 difference is significant and above 5 the difference is very large.

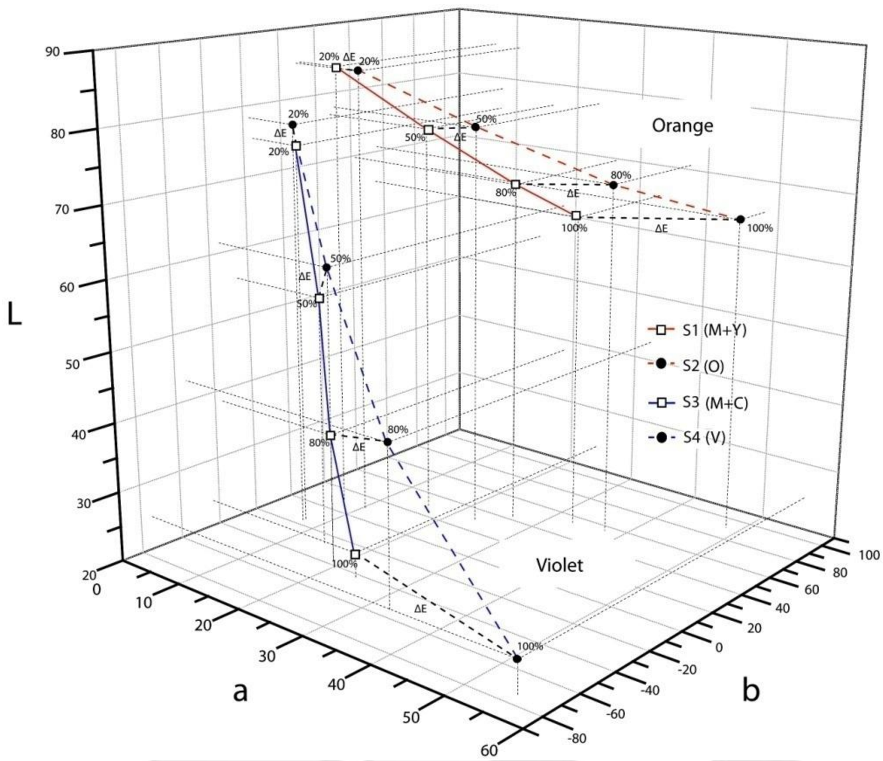

Figure 5. Display of characteristic orange and violet tones on glossy fine art paper (Magno star Gloss)

Different way of printing purple and orange tones will show on glossy fine art paper great differences in color ΔE*, lightness ΔL*, chroma ΔC* and hue ΔH*. With increase of tone values will come to the increased differences in color. In brightest values of violet (20% tone values) realized in two different ways, the difference in color is ΔE^*_{Violet}=2,71. This difference is moderate and poorly visible to the human eye. The difference in chroma (ΔC^*_{Violet}=1,14) and hue (ΔH^*_{Violet}=1,11) are a small differences. Significant changes were made by coordinate of lightness (L*) where the value grows when printing with spot violet ink. Different way printed violet (100% tone value) will have a very big difference in color and chroma (ΔE^*_{Violet}=10,27, ΔC^*_{Violet}=9,99), however lightness and hue are not changed significantly (ΔL^*_{Violet}=0,75, ΔH^*_{Violet}=2,23).

With orange tones such printing will provide greater color changes in small tone values, but minor changes with the greater tone values in relation to the violet tones. In most brightness orange tones (20% tone values) color differences is ΔE^*_{Orange}=4,73, which is difference visible to the human eye. Change in lightness (ΔL^*_{Orange}=0,11) is not significant, while in the chroma and hue is significant (ΔC^*_{Orange}=2,13, ΔH^*_{Orange}=4,22). By increase of the tone value will lead to a significant increase in the color differences which is particularly evident at 100% tone value, where the color difference and chroma are very large (ΔE^*_{Orange}=8,8, ΔC^*_{Orange}=8,34), but the lightness and hue are small (ΔL^*_{Orange}=0,08, ΔH^*_{Orange}=2,8).

Table 3: Values ΔE*, ΔL*, ΔC* i ΔH* of samples printed on glossy fine art paper (Magno star Gloss)

Sample	ΔE	ΔL	ΔC	ΔH
20%RTV Orange Sample 1-2	4,73	0,11	-2,13	4,22
50%RTV Orange Sample 1-2	4,38	-0,74	-2,26	3,68
80%RTV Orange Sample 1-2	5,01	-0,76	-4,74	1,41
100%RTV Orange Sample 1-2	8,8	-8,34	-8,34	-2,8
20%RTV Violet Sample 1-2	2,71	-2,19	-1,14	1,11
50%RTV Violet Sample 1-2	6,34	-5,05	-3,16	2,18
80%RTV Violet Sample 1-2	7,37	-4,09	-6,11	0,47
100%RTV Violet Sample 1-2	10,27	-0,75	-9,99	-2,23

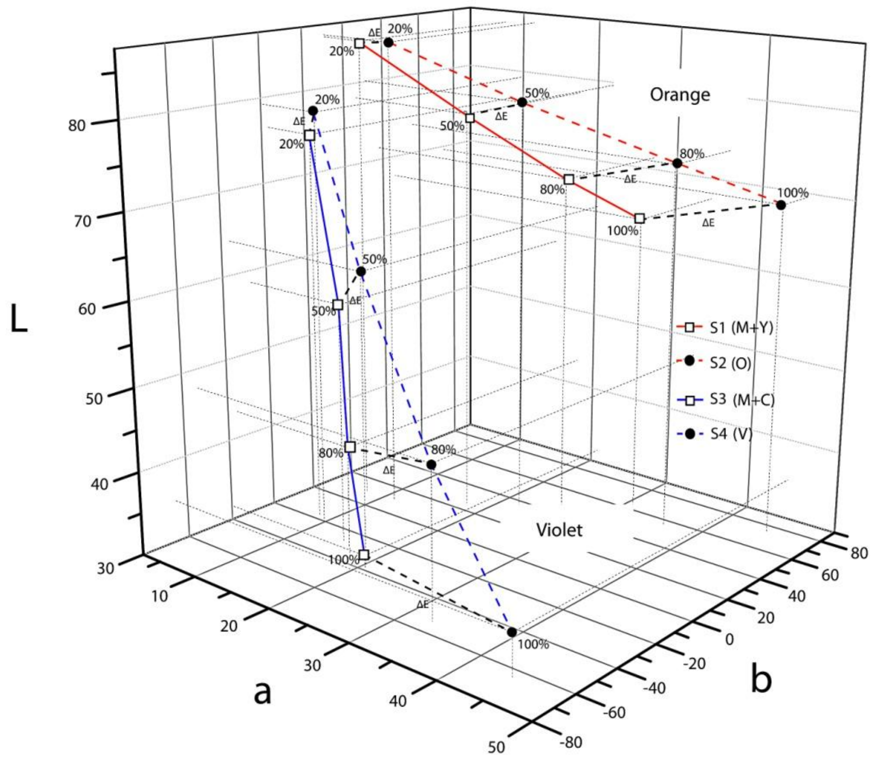

Figure 6. Display of characteristic orange and violet tones on uncoated paper (Maxio set)

On uncoated paper color differences between the tones were expected less. On Fig. 6. are displayed differences with violet and orange tones made by using different printing methods. In bright violet tones (20% tone value) differences in color and lightness are moderate (ΔE^*_{Violet}=2,7, ΔL^*_{Violet}=2,03), while in the chroma and hue negligible

(ΔC^*_{Violet}=1,72, ΔH^*_{Violet}=0,41). Compared to 100% tone value, where the color difference and chroma are very large (ΔE^*_{Violet}=9,02, ΔC^*_{Violet}=8,53), moderate lightness (ΔL^*_{Violet}=2,66), and a small hue difference (ΔH^*_{Violet}=1,22).
With brightest orange tone values (20% tone value) color difference is ΔE^*_{Orange}=3,89, which is a visible difference. If it is observed difference in lightness, the difference is negligible (ΔL^*_{Orange}=0,17), where the chroma and hue differences are moderate (ΔC^*_{Orange}=2,5, ΔH^*_{Orange}=2,97). By increasing of the tone value will lead to a significant increase in the color differences between orange tones. The biggest changes are in full tone (100% tone value), where the differences in color and chroma are very large (ΔE^*_{Orange}=7,82, ΔC^*_{Orange}=6,73), small in lightness (ΔL^*_{Orange}=1,58), while the difference in the hue is moderate (ΔH^*_{Orange}=3,65).

Table 4: Values ΔE*, ΔL*, ΔC* i ΔH* of samples printed on uncoated paper (Maxio set)

Sample	ΔE	ΔL	ΔC	ΔH
20%RTV Orange Sample 3-4	3,89	-0,17	-2,5	2,97
50%RTV Orange Sample 3-4	3,47	-1,29	-3,03	1,09
80%RTV Orange Sample 3-4	6,09	-1,65	-5,59	-1,76
100%RTV Orange Sample 3-4	7,82	-1,58	-6,73	-3,65
20%RTV Violet Sample 3-4	2,7	-2,03	-1,72	0,41
50%RTV Violet Sample 3-4	6,07	-4,75	-3,48	1,46
80%RTV Violet Sample 3-4	7,48	-4,17	-6,2	-0,29
100%RTV Violet Sample 3-4	9,02	-2,66	-8,53	-1,22

5. CONCLUSIONS

Analysis of gamut (ΔV) has shown that the printing with spot inks (O and V) significantly increase the gamut of reproduction than standard (CMYK) printing. Printing of orange spot ink gives incised gamut volume in yellow, orange and red areas, while the printing of violet spot ink results in an increase in the blue and magenta area.
Further analysis of screen value surfaces shows that increasing of the screen values leads to proportional growth and differences in color that are more visible with violet. On the basis of these results it is recommended that the orange and violet spot inks should be used only for tones of colors that have color differences greater than 3 ($\Delta E^* = \geq 3$). For small screen values the effect is small and the price is high. By analyzing the impact of the printing substrate can be concluded that it significantly affects the quality of the reproduction. By comparing the samples printed in standard way and samples printed in IndiCrome, it is evident that the coated paper substrate will achieve higher gamut volume then uncoated paper substrate.

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