The Effects of Different Printing Pressure Level Application on Sheet-fed Offset Print Quality

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In sheet-fed offset printing technique, a sufficiently high contact pressure between blanket and impression cylinders needs to be applied for the proper ink transfer onto printing substrate. The aim of this research is to investigate dependence of various print quality parameters on three printing pressure levels applied, between blanket and impression cylinders, during four color sheet-fed offset printing process on matte-coated paper. This was examined by measuring various control elements of the prints, in order to obtain quantitative information about standard print quality parameters. Through the evaluation of this important printing factor and relating it to the print quality, it will be possible to find out in which ways and to what extents different printing pressue levels affect sheet-fed offset print quality.

1. Introduction

Printing pressure between blanket and impression cylinders is very important factor for ink transfer in sheet-fed offset printing process, and therefore has a big impact on final quality of the prints. For the purpose of ink and dampening solution transfer from one surface onto another, application of optimal pressure intensity as well as even pressure distribution between blanket and impression cylinders are crucial factors. Print quality depends on various factors such as: printing plate, blanket of the blanket cylinder, printing substrate, ink, printing speed, dampening solution, ink-water balance, printing press condition and operator actions [1].

In regard to printing substrates, there are several paper properties that mostly affect offset print quality: surface roughness, surface compressibility and viscoelasticity of paper surface. Paper surface is made of fibres, that form surfaces with higher roughness profile, and the areas in the lower level recesses (holes, voids and cavities), that are not covered by ink, which can result in the uneven ink film transfer on the paper surface [2]. The higher the printing pressure the larger the area of the paper surface which can come into contact with the ink on the printing surface, thus improving ink coverage. The ink transfer within the printing nip is dependent upon the properties of the nip pressure geometry, ink rheology and the ink amount on the blanket [2]. By increase of core roughness (Sk - surface rougness parameter) of the paper, an exponential development of missing dots in the prints was noticed. As well, surface deformability of the paper (determined as an reaction of the paper surface during pressure build-up) is more important parameter for good print result than overall paper compressibility (calculated based on the thickness reduction) [3]. If solid-tone areas are printed with enough available ink, the effect of surface structure on print quality can be thereby compensated. There is a strong relationship between surface structure, deformable behaviour of certain papers under load, blanket characteristics and print quality [4, 5].

The offset printing process is dependent on the pressure in different contact zones, for example: between ink rollers; between dampening rollers; between ink form and dampening form rollers on one side and plate cylinder on the other; between plate and blanket cylinders, and in the end between blanket and impression cylinder [6]. Contact formed in the printing nip is dependent on the nip dwell time, i.e. time that sheet of paper spends in a contact zone between the cylinders, and the nip pressure [7]. Ink coverage and evenness of solid-tone areas can be improved by increasing nip pressure, because surface compression increases the surface contact area and decreases the surface roughness of the paper. In the printing nip, paper compresses and its surface becomes smoother (coldset web offset printing) [8, 9].

There are various methods for printing pressure estimation in offset printing process. One of them is based upon Prescale film, which is a two-sheet film sensitive to pressure that has to be mounted in the contact zone between an impression and a blanket cylinder. When pressure is applied, micro capsules on the first sheet crack and color-forming material reacts with color-developing material on the other sheet of the film. Level of formed ink density will depend on the intensity of applied pressure. After color is generated, printing pressure as well as pressure distribution can be estimated by ink deepness readings [6]. Pressure in a deformable nip zone of counter-rotating rolls can be also determined by means of a force measuring device, piezoelectric transducer, installed in the surface of the backing roll [10].

The aim of this research is to determine how different printing pressure levels applications between blanket and impression cylinders (which was accomplished by varying gaps between them), affect four color sheet-fed offset print quality, which will be conducted through examination of various print quality parameters, measured both on printing plates and matte-coated paper prints.

2. Materials and Methods

This research includes examination of six print quality parameters for sheet-fed offset printing technique, measured on matte-coated paper prints under three different printing pressure levels aplication between blanket and impression cylinders. Selected print quality parameters are:

1. Tone value increase (TVI),
2. Gray balance,
3. Solid-tone optical ink density deviation,
4. Relative print contrast,
5. Color gamut,
6. Color differences (ΔE).

2.1. Blanket cylinders hardness and printing pressure measurements

Overall blanket hardness of all four Flint Group day-Graphica 3610 blankets was measured using Shore durometer PCE-DX-A, which amounted 82° Shore A. For some reason measured overall blanket hardness was higher by 3° Shore A than the upper limit given by the producer specifications (79° Shore A). Afterwards, semi-dynamic printing pressure measurements between blanket and impression cylinders were performed using a Nip Control Pressure Indicator (nip widths were not measured). That means that both cylinders were rotating at slow speeds during measurements, since the shape of the rubber blanket changes when the cylinder is in motion. This instrument measures a pressure range of 200 – 700 N/cm², and a has a repeatability of +/- 10 N/cm² [11, 12]. As a first step, before the beginning of printing pressure measurements, Nip Control Pressure Indicator was calibrated using its own calibration tool. Recorded printing pressure values in the first printing unit (K) were served as references for the following three units (C, M, Y), so gaps between the cylinders were adjusting until the desired printing pressure values were achieved, in order to accomplish approximate printing pressure values in each printing unit for every printing pressure level. Three measurements were taken on three different positions of each printing unit, two on the sides of the cylinders and one in the center of each printing unit, for each printing pressure level (total of 108 measurements). Three different printing pressures between blanket and impression cylinders were applied on each printing unit: low printing pressure level, normal printing pressure level, and high printing pressure level. All the applied printing pressure levels correspond to appropriate gaps between blanket and impression cylinders as following: 0.12 – 0.16 mm (low printing pressure level), 0.08 – 0.12 mm (normal printing pressure level), and 0.04 – 0.06 mm (high printing pressure level), Table 1. Although very important parameter in print production, inking units settings were not taken into account. When the appropriate print densities were achieved for one printing pressure level, the same adjustments of the all inking units were used for each other printing pressure level application.

Total circulation of 200 sheets were printed by sheet-fed offset KBA Rapida 75 printing machine using FUJIFILM Brillia LP-NV negative acting printing plates (circular dot shape, AM screening) and TOYO (TK HU NEO ERP) process inks on matte-coated paper (115 g/m2), under ideal atmospheric printing conditions in the press room (relative air humidity of 52% and air temperature of 21°C) under printing speed of 7.000 sheets/h. Ink sequence was black, cyan, magenta and yellow (KCMY). Before printing of actual job, printing machine was brought in optimal state by printing approximately 100 sheets in order to set inking units. When the job was printed random sampling of the prints took place and three sheets were taken for each printing pressure level applied (total of 9 sheet samples). When the printing pressure measurements and printing of the samples were done, six standard print quality parameters were measured. Different print quality control elements were measured for each desired parameter, Figure 1. Print quality parameters determination was conducted using different measuring devices: TECHKON SpectroPlate (digital microscope) and SpectroDens (spectro-desitometer), VIPTRONIC VIPDENS 2000 (reflection densitometer), GretagMacbeth Spectrolino (spectrophotometer),

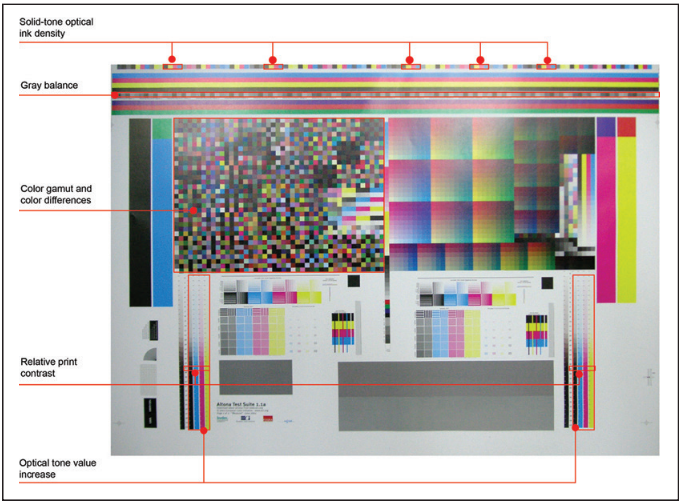

Figure 1: Measured control elements of the matte-coated paper print

and softwares GretagMacbeth ProfileMaker Pro 5.0.5 (Measure Tool and Profile Maker) and Chromix Color Think Pro 3.0.

2.2. Tone Value Increase – TVI

Tone value increase values were measured on TV patches of matte-coated prints (vertical control bars on both sides of the printed sheets containing TV patches from 0% – 12% with steps of 1%, 20% – 80% with 10% steps, and TV patches from 88% – 100% with 1% steps), and mechanical dot gain on the same TV patches but only on the plates, Figure 1. Two TECHKON measuring devices were used, digital microscope SpectroPlate for obtaining mechanical dot gain, with settings adjusted to correspond considered printing plates, and spectro-desitometer SpectroDens for TVI measurements, with following settings: polarizing filter – auto, white reference – auto, density filter – ISO/ANSI II, illuminant D50, observer 2°). There were total of 432 TVI measurements (9 TV patches x 4 colors x 2 sides of the sheet x 3 printing pressure levels x 2 sampled sheets for each printing pressure level) and 72 mechanical dot gain measurements of the plates (9 TV patches x 2 plate sides x 4 printing plates), after which obtained results were averaged and analysed.

2.3. Gray balance

For gray balance parameter estimation, ECI/bvdm Gray Control Strip (S) was used, Figure 1. Results in this research were obtained by the means of densitometric measurements of relative optical ink density values on different TV gray balance patches (30%, 50%, and 70%) using VIPTRONIC VIPDENS 2000 measuring device (applied settings: illuminant D50, standard observer 2°). There were total of 81 measurement, 3 different TV patches x 3 positions of each TV patch on the sheet x 3 printing pressure levels x 3 samples for each printing pressure level. Afterwards, in order to verify obtained results, spectrophotometric measurements were conducted using TECHKON SpectroDens. There were total of 360 measurements: 3 different TV patches (70%, 50% and 30%) x 2 patch types (CMY and black) x 20 measurements on three paper samples x 3 printing pressure levels. Then, color differences ΔE94 values were calculated between chromatic gray balance (CMY) patches and achromatic (K) patches of the appropriate tone values on the samples printed with the same printing pressure level.

2.4. Solid-tone optical ink density deviation

This parameter was obtained using TECHKON SpectroDens measuring device (same settings as mentioned above) on the solid-tone patches of horizontal control bar, Figure 1. There were total of 120 measurements (10 measuremants per color x 4 colors x 3 printing pressure levels).

2.5. Relative print contrast

A key parameter for calculating relative print contrast values is optical denstity. Those values were obtained by measuring TV patches of 100% and 80% using VIPTRONIC VIPDENS 2000 device (applied settings: illuminant D50, standard observer 2°). Total of 72 measurements were performed; 2 measurements for each color x 4 colors x 3 printing pressure levels x 3 sheet samples for each printing pressure level.

2.6. Color diffrences (ΔE) and color gamut

For the purpose of color gamut volume and color differences measurements ECI2002V CMYK PM 5.0.5 testchart was used. As a measuring device, GretagMacbeth spectrophotometer, Spectrolino was used for color sampling (applied settings: illuminant D50, standard observer 2°), as well as GretagMacbeth ProfileMaker Pro 5.0.5 software, Measure Tool and Profile Maker for subsequent color profiles generation and obtaining information about ink color differences. Settings used in profile generation were following: Profile size – large; Perceptual rendering intent – paper, colored gray; Gamut mapping – Logo classic; Separation – GCR 40 -100 -400; Viewing light source – D50 and Correction for optical brightener option was checked. There were 4,455 measurements in total (1,485 patches on each test chart x 3 printing pressure levels). Then profiles were compared to the reference one, in order to determine differences in color gamut and color deviations in Chromix Color Think Pro 3.0 software, as well as to generate 2D representations of extracted profiles. Color difference values were calculated using ΔE94 formula, which is a recomendation given by this software.

3. Results and Discussions

In this section of the paper, the analysis of six offset print quality parameters results will be presented and discussed, in order to determine their dependancy on applied printing pressure level and which printing pressure level generates the best print reproduction for a specified print quality parameter.

3.1. Printing pressure values analysis

Three different printing pressure levels were applied between blanket and impression cylinders in printing process by varying distances (gaps) between them: low printing pressure, normal printing pressure and high printing pressure. Measured printing pressure values for each printing unit (left values), and values of gaps adjusted between cylinders (right values) are presented in Table 1. It was endeavoured to apply printing pressure as uniform as possible on each printing unit, but there were certain deviations between them (8.89% – 13.85%). The maximum printing pressure values were recorded on printing unit that prints magenta ink. Generally, the lowest printing pressure was recorded on yellow printing unit.

3.2. Tone value increase analysis

3.2.1. Mechanical dot gain of the printing plates

Mechanical dot gain values measured on the printing plates are presented in Table 2. They show that all TV are reproduced correctly, without bigger increases or tone value drops. Maximum positive TV deviation is 1.25%, recorded on the 20% TV patch of yellow separation, and a maximum negative TV deviation is 1.75% (smaller TV than aimed), measured on the 50% TV patch of cyan separation. The lowest overall TVI values are recorded on cyan separation, while the highest values were recorded on yellow separation, though TV of all four separations are quite uniform.

3.2.2. Tone value increase (TVI)

Obtained TVI values as well as aimed ISO TVI values (purple lines and dashed purple line for black ink separation) which correspond to defined printing conditions (printing process, screen ruling, paper and printing plate types) according to ISO 12647-2:2004 standard are presented in Figure 2. As a result of higher printing pressure level application (red curves), generally, higher TVI values are produced. Exception is cyan separation where

Ink	Low printing pressure		Normal printing pressure		High printing pressure	
C	372.20	0.14	562.17	0.10	695.51	0.04
M	422.22	0.16	591.11	0.12	712.22	0.06
Y	366.67	0.12	547.78	0.08	668.89	0.04
K	401.11	0.12	536.67	0.08	650.00	0.04

Table 1: Printing pressure values [N/cm2] – left columnes, and gaps between the cylinders [mm] – right columnes, for each printing unit and applied printing pressure level

	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	avg. TVI [%]
Cyan	9.95	20.20	29.65	38.70	48.25	59.50	68.80	79.20	89.00	- 0.75
Magenta	10.55	20.85	31.05	39.90	48.40	59.80	69.60	79.80	89.50	- 0.06
Yellow	10.45	21.25	30.60	40.20	48.95	60.20	69.90	80.25	89.60	0.16
Black	10.70	20.85	30.85	39.60	48.85	60.35	69.50	79.60	89.45	- 0.03

Table 2: Mechanical dot gain and avg. TVI values [%] measured on offset FUJIFILM Brillia LP-NV printing plates

normal printing pressure level (green curves) produced the highest TVI values for all considered TV patches, as well as on 90% TV patch of magenta ink separation, 70%, 80% and 90% TV patches of yellow ink separation and 90% TV patch of black ink separation. The smallest TVI values were generated using low printing pressure (yellow curves), except on 60% and 70% TV patches of black ink separation, which TVI values were higher than those produced using normal printing pressure level. All mentioned TVI differences are quite small, and do not exceed TVI value of 0.60%.

The highest TVI values were recorded within the black ink separation (which is a common case due to the fact that it was printed in the first printing unit and often with greater ink film thickness) Figure 2. d), even though a black separation (K) was printed using the smallest printing pressure amount, considering normal and high printing pressure settings. The smalest TVI values were obtained on cyan prints, which were printed by the second highest printing pressure amount and the lowest mechanical dot gain of the plates. Similar TVI was recorded within magenta and yellow ink separations. Shapes of generated TVI curves for different printing pressure levels are as well very similar for each separation, which shows consistent ink transfer during printing process.

In regard to given aimed ISO values for chromatic inks (purple curve) and for black ink (dashed purple curves), it can be observed that each printing pressure level produced higher TVI values in highlights (C 10% and 20% TV patches; M 10% – 30% TV patches; Y 10% – 30%) of chromatic colors, while within black ink separation TVI values are higher in mid-tones as well (K 10% – 60% TV patches). On the other hand, each printing pressure level produced generaly lower TVI values in shadows (70% and 80% TV patches) for all separations.

TVI values measured on 40%, 50% and 80% TV patches of all separations fit in the tolerance values range, that are given in Table 3.

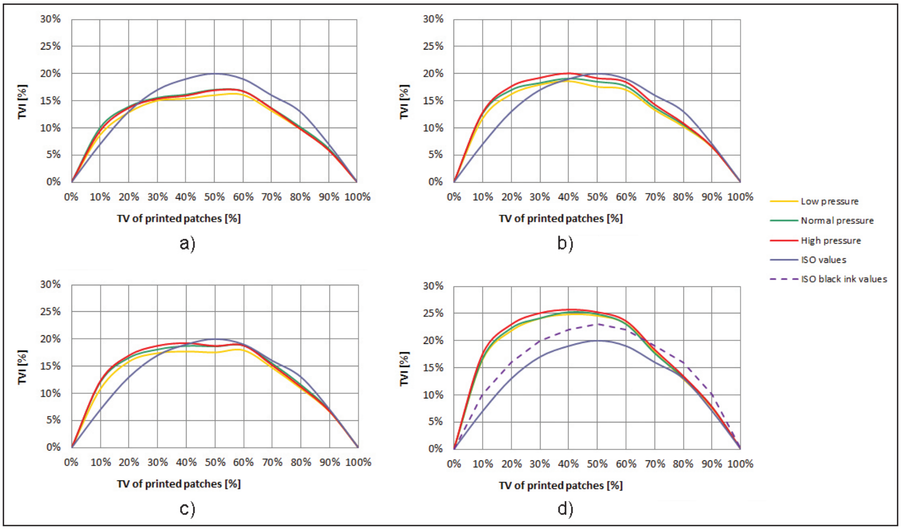

Figure 2: Tone value increase: a) Cyan ink, b) Magenta ink, c) Yellow ink and d) Black ink

Tone value of control patch	Variation tolerance
40 or 50	4
75 or 80	3

Table 3: Tone-value increase tolerances [%] according to ISO 12647-2 [14]

It is difficult to determine which printing pressure level produced the best overall performance in terms of TVI parameter, but considering given tolerance values for specific TV patches as well as rest ISO TVI values as a criterion, different printing pressure levels produced different result for different separation. High printing pressure level produced the best TVI values for magenta ink separation (second best for cyan, yellow and black ink separation); normal printing pressure level showed as a best option for cyan and yellow ink separations (second best for magenta and third for black ink separations); low printing pressure level genrated the best results for black ink separation (worst for the rest three separations).

Analysed TVI results showed that there is no one specific printing pressure level that can be applied on each printing unit in order to produce the desired TVI results, rather it was found that various printing units need different printing pressure level application.

3.3. Gray balance analysis

Obtained gray balance values are presented in function of three process inks (C, M, Y) optical density values, measured on three different TV patches (30%, 50% and 70%), Table 4, as well as via their CIE L*a*b* coordinates, Table 5. For gray balance determination ECI/bvdm Gray Control Strip (S) was used which consisted of three patch pairs. Each pair consists of a gray balance patch printed with three process inks (C, M, Y) and a patch prited solely with black ink. The aim was to match the chromatic gray patches to the true gray patches by adjusting printing pressure levels, i.e. gaps between blanket and impression cylinders. For achieving ideal gray balance, concerning the first measurement method, all three optical ink density values of used process inks for each control patch (30%, 50% and 70%) shoud be as much as uniform. This was verified by calculating standard deviation values (σ) between the three averaged optical ink density values for appropriate TV percentage and printing pressure level, Table 4. A dominant color of the prints, i.e. its optical ink density, is yellow, for each measured gray balance TV patch and pressure level applied, which indicates that a disbalance of optical ink density values of three printed process inks is present. By increasing printing pressure, optical ink densities of all three inks generaly increase too. The optical ink density differences between dominant ink (Y) and the other two inks (C, M) do not behave on predictable pattern. Namely, the smallest deviation between optical density values were recorded on a gray balance TV patch of 50%, printed using normal printing pressure level, but very similar results were obtained using low and high printing pressure for this TV patch. On the second control TV patch (50%), low printing

TV	Printing pressure level	C	M	Y	σ
30 %	Low	0.344	0.333	0.393	0.0320
	Normal	0.338	0.334	0.390	0.0313
	High	0.360	0.347	0.409	0.0328
50 %	Low	0.547	0.545	0.645	0.0573
	Normal	0.553	0.555	0.659	0.0610
	High	0.582	0.573	0.683	0.0608
70 %	Low	0.858	0.819	0.959	0.0725
	Normal	0.876	0.836	0.980	0.0741
	High	0.889	0.874	0.985	0.0708

Table 4: Optical ink density and standard deviation values of the matte-coated paper prints

TV	Printing pressure level	Gray balance patch			Black patch			ΔE94
		L*	a*	b*	L*	a*	b*	
30 %	Low	40.07	-1.56	-0.40	39.76	-0.11	-1.00	2.32
	Normal	39.77	-2.08	-0.35	38.33	-0.23	-0.81	2.53
	High	39.03	-2.26	-0.90	37.43	-0.18	-0.67	2.50
50 %	Low	54.03	0.87	-0.17	51.59	0.05	-1.53	2.91
	Normal	53.98	0.31	0.08	50.63	-0.07	-1.46	3.71
	High	52.94	0.53	-0.28	49.82	-0.03	-1.18	3.30
70 %	Low	68.04	1.82	-1.28	66.78	0.30	-2.49	1.59
	Normal	68.05	1.28	-1.16	66.20	0.14	-2.45	2.38
	High	67.17	1.57	-1.13	65.32	0.20	-2.10	2.64

Table 5: Calculated ΔE94 values between chromatic gray balance (CMY) and achromatic (K) patches

pressure level produced the most balanced optical ink density values, which indicated σ value of 0.0573. 70% gray balance TV patch reveals that the best result was produced under high printing pressure level (σ=0.0708). Each printing pressure level generated similar result, but each of them produced the best gray balance for different TV patches. It can be noted that there is no predictable changing trend of gray balance values with the pressure level shifts, as well as that differences between calculated standard deviations are very slight, therefore a printing pressure level change did not affect gray balance parameter of the prints in greater extent. For the verification of obtained gray balance data, spectrophotometric method was used as well for gray balance measurements in the part of the paper that follows.
In Table 5. are presented L*a*b* and color differences (ΔE94) values, calculated between measured L*a*b* values of the same TV chromatic (CMY) grey balance patches (30%, 50% and 70%) and achromatic patches printed using the same printing pressure level.
These results do not support previously obtained results based on densitometric evaluation. According to presented ΔE94 values, low printing pressure level produced the smallest color differences on each grey balance patch; high printing pressure level generated the second best color differences results (second best results for 30% and 50% grey balance patch); and the last one is normal printing pressure, which produced one second best result for 70% TV gray balance patch.
If we acknowledge spectrophotometric results as a more accurate and reliable, then low printing pressure level should be the most appropriate one.

3.4. Solid-tone optical ink density deviation analysis

In Table 6. are presented standard solid-tone optical ink density values for sheet-fed offset printing process, which were taken as a reference ones for standard deviations calculations (formula 1). Average solid-tone optical ink density values, and calculated standard deviations from the reference solid-tone optical ink density values for each process ink and printing pressure level are presented in Table 7.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \mu\right)^2} \qquad (1)$$

where
σ – standard deviation,
N – total number of measurements (10 for each ink x 3 for each printing pressure level),
x_i – optical ink density value of the i^{th} measurement,
μ – reference value for appropriate ink (Table 6).

It is already observed that when the contact pressure between impression and blanket cylinders increases, ink deposition on the substrate will also rise, which results in higher optical ink density values. By increasing pressure amount in printing process, generally higher solid-tone optical ink density values were produced. The exception is printing pressure level shift from low to normal on the yellow and black (Y, K) solid-tone patches. Next printing pressure level shift, from normal to high printing pressure, produced expected, higher solid-tone optical

Paper type	Ink			
	Cyan	Magenta	Yellow	Black
Matte-coated wood-free	1.45	1.4	1.25	1.75

Table 6: Recomended solid-tone optical ink density values according to ISO 12647-2 [13]

Printing pressure	C	σ_C	M	σ_M	Y	σ_Y	K	σ_K
Low	1.480	0.0508	1.392	0.0597	1.423	0.1750	1.721	0.0746
Normal	1.498	0.0500	1.411	0.0493	1.417	0.1679	1.709	0.0577
High	1.554	0.1117	1.459	0.0967	1.436	0.1883	1.759	0.0448

Table 7: Solid-tone optical ink density values and standard deviation values

ink density values for all process inks. This was also confirmed for all measured TV patches except for 30% cyan and yellow ink separation TV patches using normal printing pressure, in the previous section (Table 4). Standard deviation values show declinig trend after the first printing pressure level change from low to normal, Table 7 and Figure 3. Normal printing pressure level generated the smallest solid-tone optical ink density deviations for three process inks (CMY). After second printing pressure level increase, standard deviation values went up, with the exception of black ink separation, where was recorded the smalest standard deviation value.

Printing pressure increase from low to normal, did not prove theoretical grounds and lead to optical ink density values increase, instead it produced lower optical ink density values for yellow and black inks, and generated generaly the lowest standard deviations from the reference values. Further printing pressure level increase, from normal to high genrated the highest solid-tone optical ink density values, which supported the theory, but generaly the highest standard deviation values.

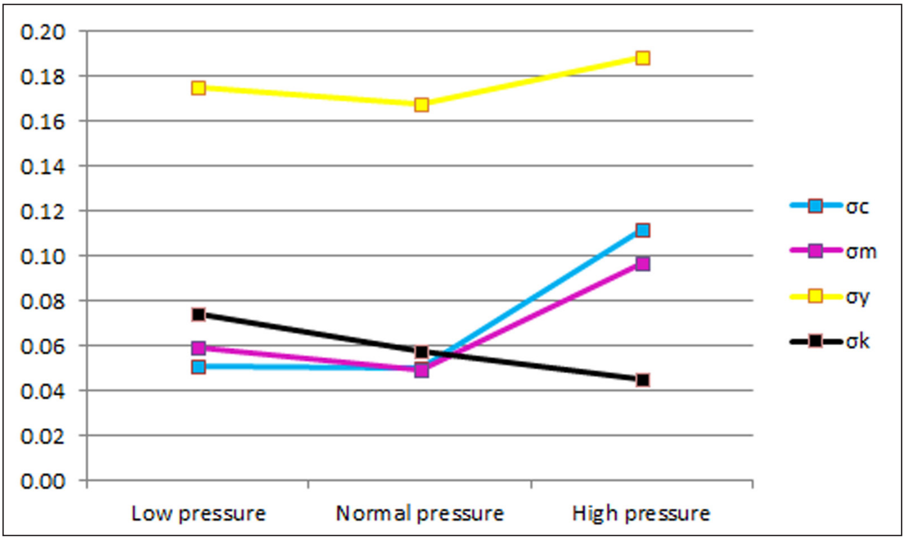

Figure 3: Solid-tone optical ink density standard deviation values (σ) for each process ink and printing pressure applied

3.5. Relative print contrast analysis

In Table 8. are presented relative print contrast values for each process ink and printing pressure level applied. This print quality parameter was obtained by measuring optical ink density values on solid-tone and 80% TV patches, and then calculating it using following relative print contrast formula:

$$K = \frac{D_s - D_t}{D_s} x\, 100\, [\%] \qquad (2)$$

where
D_s – optical density of solid-tone patch,
D_t – optical density of halftone patch (80%).

Obtained relative print contrast values are smaller than the reference ones: C 43%, M 38%, Y 38%, K 33% [15] for each printed process ink and printing pressure level applied, with an exception of black ink, which produced higher relative print contrast values for all printing pressure levels. The smallest relative print contrast values were produced using normal printing pressure level. High printing pressure level generated the highest relative print contrast values for all four process inks, as well as the smallest differences from the given reference values, which suggests that for the best relative print contrast reproduction on matte-coated papers high printing pressure level should be used.

Explanations for gaining these relative print contrast values may be found in the assumption that surface structure of considered paper type as well as thickness of coating layer applied were inconsistent. In areas of paper where is present uneven coating layer thickness occur non-uniform lateral light scattering which leads to tone value and optical ink density increase. Non-uniform lateral light scattering over different areas of the same paper sheet can be observed microscopicaly, as well as by printing a sequence of paralel lines with the appropriate thicknesses and gaps between them on the paper, after which optical density of the gaps is measured using micro densitometer, and microdensity profile is generated. It will show greater optical density of the paper in the regions with thinner coating layer, comparing to those areas which are covered with higher thickness of the coating layer [16].

3.6. Color gamut and color differences (ΔE94) analysis

Different printing pressures generate different color gamut volumes, which is in relation to various ink thicknesses transfered onto the substrate material, resulting in different optical ink density of the prints. High printing pressure level application in the printing process produced the biggest color gamut volume; normal printing pressure level generated lower color gamut volume, while the lowest color gamut volume was produced using low printing pressure level, Table 9.

Color gamut volumes comparisons between values obtained using different printing pressure levels application were also presented in Figure 4. From the figure it can be observed that generated color gamut volumes using three printing pressure levels are almost matching, though slightly wider color gamut volume can be noticed by using high printing pressure level (red line) comparing to other two data sets (green line – normal printing pressure level, and yellow line – low printing pressure level).

Color difference values were calculated using CIE 94 (ΔE94) formula, Table 9. Test results show that generaly the smallest color difference values (ΔE94) were achieved using high printing pressure level (except yellow ink printed with low printing pressure), while normal printing pressure generated generaly maximum color differences. Concerning color difference tolerances accepted in print industry, calculated color differences for cyan and yellow ink fall into category of normally invisible differences (ΔE94<1) for all three printing pressure levels applied; calculated color differences for magenta ink are in the third group of medium differences, which are obvious to an untrained eye (2<ΔE94<3.5), and color differences for black ink belong to group of an obvious differences (3.5<ΔE94<5). Calculated color differences between different printing pressure levels for each printed ink do not differ more than 0.63 (black ink), which is practically invisible color difference for human perception. So even if it is hard to differentiate obtained variations of these two print quality parameters produced by three different printing pressure levels visualy, data suggest that high printing pressure level provided slightly better performance.

Printing pressure	C	M	Y	K
Low	38.17 %	35.17 %	34.33 %	39.00 %
Normal	37.00 %	35.50 %	33.33 %	37.83 %
High	39.50 %	36.17 %	34.50 %	39.67 %

Table 8: Relative print contrast values

Printing pressure	Color gamut volumes	ΔE94			
		Cyan	Magenta	Yellow	Black
Low	370,812	0.65	3.26	0.71	4.45
Normal	372,717	0.52	3.29	0.84	4.44
High	379,168	0.44	3.14	0.79	3.82

Table 9: Color gamut volumes, color differences (ΔE94) between measured samples and reference test target data

4. Conclusions

After investigation on how different printing pressure levels affect sheet-fed offset print quality, and a prediction that printing pressure level change will have a great impact on different print reproduction parameters, we have come to certain conclusions. Applied printing pressure levels influenced some print quality parameters in a lesser while the others in a greater extent, as well as that there was no clear trends of how print quality degrades or improve with the same printing pressure level change for different print quality parameters.

Obtained mechanical dot gain values on the plates show that all tone values are reproduced correctly, without bigger increases or tone value drops. Taking into account ISO 12647-2:2004 standard [13] and reference TVI values for the considered paper type, the most appropriate TVI values were achieved by using different printing pressure levels for different separations: high printing pressure level produced the best TVI values for magenta ink separation, normal printing pressure level showed as a best option for cyan and yellow ink separations, while low printing pressure level genrated the best results for black ink separation. If we rely on the spectrophotometric results, as the more accurate one, and calculated color differences values (ΔE94) for gray balance parameter (Table 5.), it can be concluded that low printing pressure level produces the best grey balance result, even though a change in printing pressure level did not result in massive gray balance fluctuations between the samples printed using different printing pressure levels. Concerning solid-tone optical ink density parameter, it was confirmed that normal printing pressure level gives the best print quality result for three out of four separations (CMY), while high printing pressure level generated the best result for black (K) separation as suggesting calculated standard deviation values in Table 7. The best relative print contrast and color gamut volume were produced by using high printing pressure level for each separation (CMYK). The same printing pressure level generated the smallest color difference values for three separations (CMK), while low printing pressure level generated the smalest color difference only for yellow (Y) separation. Even if it was noticed that, for example normal printing pressure level had never produced the best print result within black ink separation for any considered print quality parameter, from the presented and analysed offset print quality parameters results it is very difficult to determine which printing pressure level application is the most efficient one because, as we seen different printing pressure levels had different impacts on different print quality parameters.

In order to complement this print quality characterization, further directions of research should be focused on the investigation of additional print quality parameters (dot deformation, line reproduction, visual estimation, etc.), as well as an inclusion of more variable factors that affect offset print quality (printing speed, fountain solution and inking system effects on print quality, etc.).

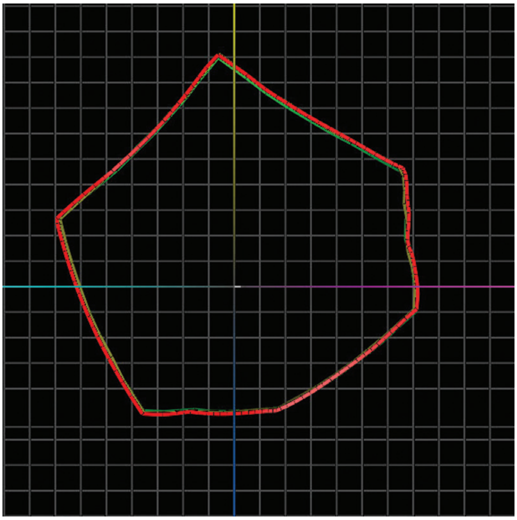

Figure 4: Color gamut volumes comparison for three different printing pressure levels

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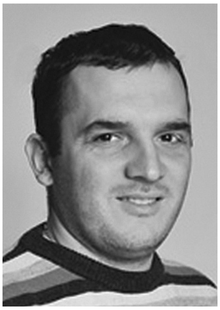

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