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THE 4-BEAM LASER DIODE ARRAY INFLUENCE ON THE COLOUR IMAGING

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Abstract: *In this paper we investigate commercial 4-beam laser diode array with 830 nm laser. Experiment was performed on HP Indigo series 1000 machine. Controlled variation of the output laser power from 1 µW/mA to 12 µW/mA generates different sizes of screen elements on photoconductor. The results have been processed colorimetrically and with defining of colour difference CIE LAB ΔE. Measurements demonstrate that gamut space ΔV doesn't change with variation of output laser power. Change of CMYK colors (solid tone) is negligible and 50% screen tone value experience up to ten times larger change of hue. Deviation of geometrical parameters of printed elements rises with enhancement of output laser power which generates overlap of raster elements for screen tone values beyond 50%.*

Key words: *digital colour offset, space gamut of reproduction, CIE LAB ΔE, image analysis*

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1. Introduction

Commonly used imaging method in electrophotographic printing process is DAD (discharged area development) method. In DAD imaging method the surface of photoconductor is exposed to prior defined electromagnetic wavelength (energy) which causes local photoelectric effect in CGT (Charge Generation Layer) layer.

The result is spatially localized electropositive potential on photoconductor surface. This spatial localization (electrostatic charges) corresponds to the latent image (charged light image) on the drum. In other words, with aid of defined light rays the printing elements are formed to be coloured later in the developing process by electropositive toner which adheres selectively on the discharged areas of the surface, thereby making the latent image visible (Landa, 1994).

Photoconductor chemical composition defines the source wavelength. This means that only the narrow part of electromagnetic spectra can generate the desired potential difference between the exposed and unexposed areas. Laser diode is common choice in the laser head construction and by varying the laser source output strength it is possible to control the photoconductor potential difference, influencing the formation quality of the thinnest image elements (digital screen dot)(Kipphan, 2001).

2. Theoretical part

Productivity of electrophotographic machines is in direct correlation with operation principles of the exposure device (laser head). The construction of the exposure device is decisive for the quality of the colour reproduction. Two basic types of the exposure devices are recently built in the machines. They are the exposure devices based on LED (Light Emitting Diode) and ROS (Raster Optical Scanner) technology.

Modulated by electrical signals from the digital printing press controller, laser beam is directed through a collimator lens system onto a rotating polygon mirror (scanner), which reflects the laser beam.

After being reflected from the scanner, laser beam pass through a scanning lens system, which makes corrections ensuring that beam remains in focus and scans it from one side of the photoreceptor to the other. The laser beam illuminate charged surface of photoreceptor with a suitable wavelength (laser/arrays of LED) selectively discharging areas of the photoreceptor previously charged with, for example, corona discharge device.

When laser beam reaches the edge of photoconductor cylinder, the photoreceptor has moved in such manner so the new beam sweeps along a new parallel path. Modulation signal from the digital printing press controller drives laser in such manner that light forms a latent electrostatic image, by means of shutting light on and of. For higher speed imaging, two or more lasers can simultaneously form image on the photoreceptor.

In LED exposition technology one light emitting diode (LED) offers the best print quality i.e. the highest resolution. It is responsible for formation of only one printing element. Such LEDs are built in bigger LED chips, generating multiple-spot beam, which are directly connected with IC driver. Depending on the number of LED chips in a block, there are two types of LED recording heads: LED heads of the 1st generation (64 LED chips in a block) with reduced resolution and speed and resolution improved LED heads of the 2nd generation (128 chips in a block)(Cheng et al., 2001).

ROS exposition devices as source typically apply lasers diodes. In order to achieve the selective exposure, laser light is modulated with external acoustic-optical modulators. Four constructions are typical for the laser heads of this type: ROS system with mirrors, ROS system with the correction optics, ROS system with dual diode laser and the ROS system with variable resolution (Schawlow, 1996).

Light sources are multiplied in order to achieve better efficiency with the ROS devices. HP Indigo printing machines of the series 1000 have the system of diode lasers which generate 4 beams and achieve the imaging velocity of 60 cm/s (Drennan, 1998).

The writing heads of HP Indigo machines series 1000 are composed of two basic units: the electronic driving unit placed on the top of the writing head and underlying, hermetically sealed, optical unit based on ROS system with the correction optics. To obtain desired speed and precision, during printing process, the electronic units send two timing signals: ready signal and separation - synchronization signal (demands sending the next separation) (Chatow & Udi, 2001).

Four laser sources work simultaneously at the speed of 1 Gbit/sec and represent 4 separate binary data transfer channels. This data are stored in the image memory board which is built on VCorn (high-performance operating strategy for self-controlled synchronous motors). System contains different signal controls needed for various calibration processes. The signals are controlled (the strengths of the laser light output and the illumination on polygon) with the intern communication interface (WHIF).Optical unit is responsible for formation and movement of laser light beam. It is composed of 7 main parts: 4 laser diodes, temperature control sensor, first optical subsystem, 18 facets polygon, second optical system, dynamic mirror and SOS (Start of Scan) detectors (Goldmann, 2004).

Light source is laser diode array matrix with four rays, driven by WHIF (Writing Head Interface), and is vertically oriented in regard to the photoconductor cylinder. Four light sources (laser diodes) are embedded in the center of the laser head housing, emitting 830 nm (IR electromagnetic field) wavelength light beams. Laser diode system is built in complex cooling device to ensure emitted intensity stability.

Cooling device consists of ribbed plate (alloy of lead and tin) built above the laser diodes, while the aluminum substrate is attached to the pure copper (material suitable for taking out the excess heat from the system) in the device base. All elements of the cooling device are in thermal contact with the laser system. Such construction ensures the constant operation temperature of the LED lasers which is one of the basic requirements for defining desired wavelength and its stability during imaging process. Temperature is monitored via control sensor placed near laser diodes array.

The four formed IR laser beams are positioned 150 µm apart with beam divergence 10^o (width) x 30^o (height). Laser diodes illuminate photoconductor cylinder in line (i.e. four lines) with the speed of 19 nsec/pixel and creates shape and size non uniform image elements (generated pixel is darker in the centre in regard to the periphery). This is the consequence that laser operates in TEM_{00} mode which gives the Gauss profile of the laser beam intensity. In this working regime the laser diodes maximally illuminate with the accuracy of 4 pixels per height (125 µm) and 1 pixel per width (32,5µm).

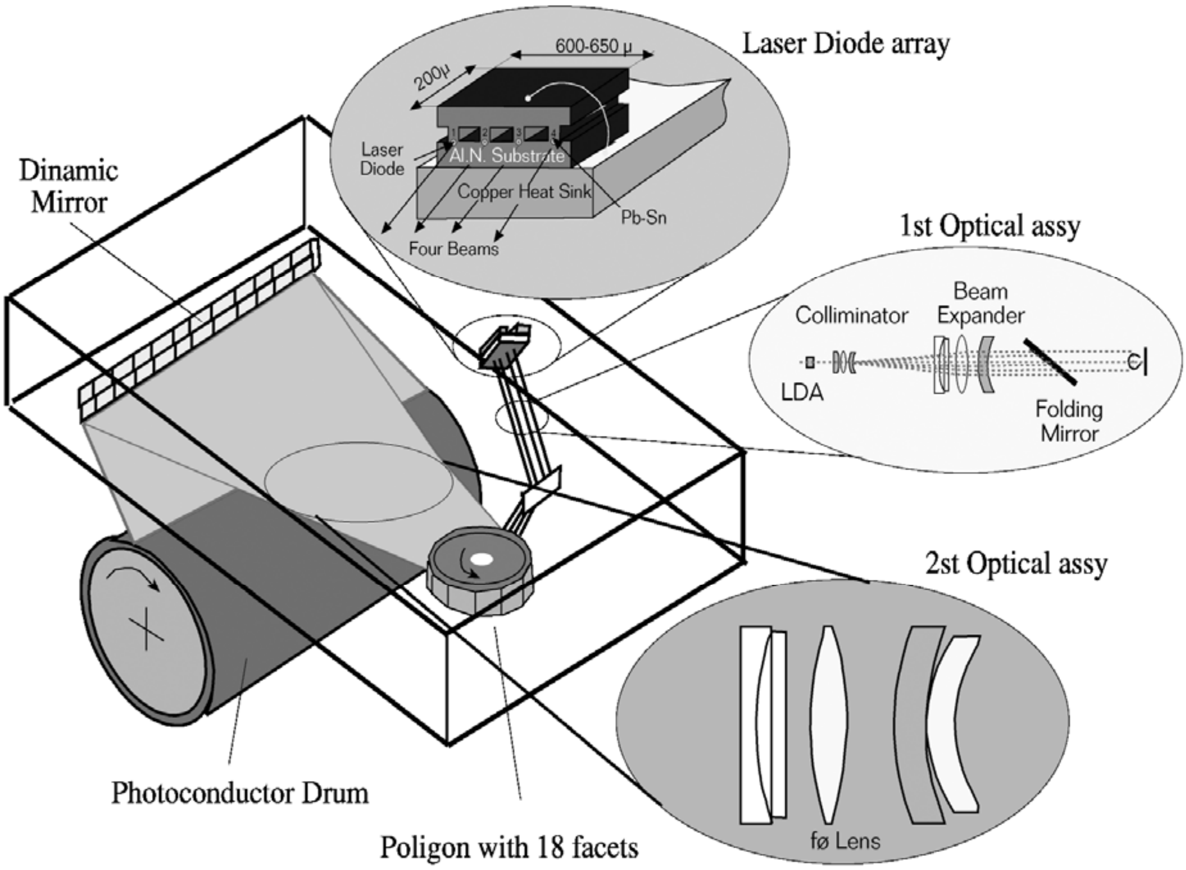


Fig. 1. 4 beams LED array of ROS laser head in body- and ground-plan

It is necessary to guide the formed lased beam to the photoconductor which must be illuminated across its whole width (330 mm). The first optical subsystem rotates outgoing beam in sense that after collimation vertically collapses laser beam at height of 100 μm, while horizontally expands from 12 mm to 36 mm. Such contracted beam is reflected from the folding mirror and ends at mirror polygon which rotates with the speed of 16269 revolutions/min. The polygon is built of 18 highly reflected facets of equal sizes which are under the angle of 160°. Such construction (the size of polygon facets) corresponds to the laser beam cross section surface which passed through the first optical subsystem. (Schein, 1996)

Rotating mirror polygon serves for horizontal scanning of photosensitive cylinder. The full rotation of the polygon scans 18 lines. During illumination, the polygon facets must be completely exposed to light, if not, a part of the output illumination power is lost (E-Print update course, 2002).

After reflection, from surface of the mirror polygon the laser light passes through the second optical system which contains spherical and cylindrical type lenses. The setting of these lenses is necessary for compensation of pyramidal error - optical phenomenon of caused by the precession of polygonal mirror.

As a result, laser beam is focused in only one point forming the shape of the future printing element on the photoconductor drum. Two optical SOS detectors (Start of Scan) control position precision of image element (You et al., 2004). Polygonal and dynamic mirrors (at the end of the second optical system) are driven by means of WHIF (Writing Head Interface). Adjustment by means of rotation of dynamical mirror will place 4 light beams (spots) in desired position on the photoconductor.

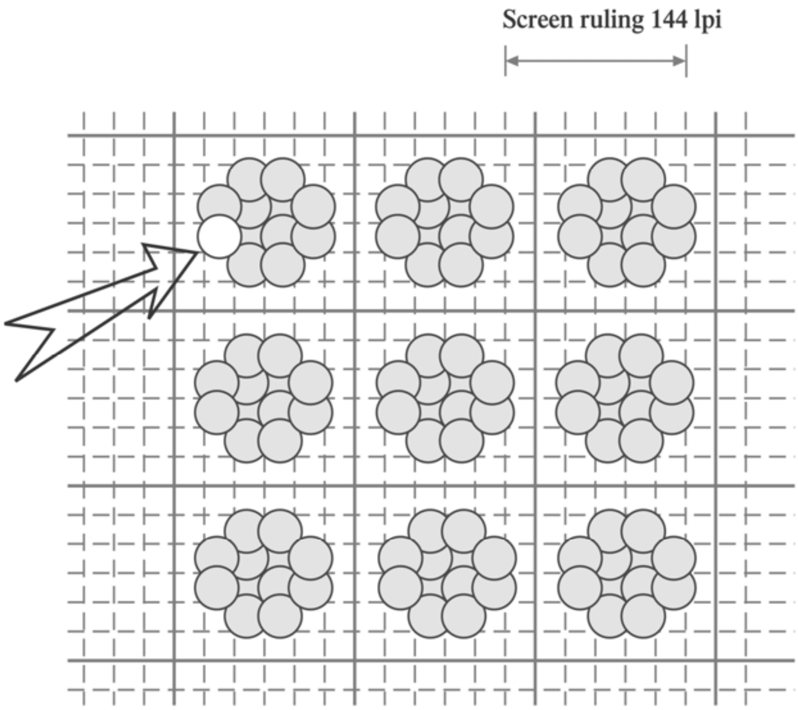


Fig. 2. Final product of the laser illumination – super pixel 6 x 6

Vertical scaling by dynamic mirror, within 0,7 mm, enable correction of 437mm format at steps of 0,1 μm, while horizontal aberration of the dynamic mirror adjust 308 mm format at steps of 66 μm.Thus, by means of the deskew correction shift of 1 μm, will be achieved precision of image shift of 1/30 pixel.

Deskew is the preprocessing operation of removing skew from images (especially bitmaps created using a scanner). Skew is an artifact that can occur in scanned images because of the optical system being misaligned, imperfections in the scanning or surface, etc.

The standard recording resolution is the final result of 812 x 812 dpi, where the matrix super pixel 6 x 6(it reduces the complexity of images from hundreds of thousands of pixels to only a few hundred superpixels) is used in formation the smallest screen element. The possible optical system defocusing of the writing head will not influence general sharpness of the printed image, but the change of focus of the writing head will considerably influence the size and the shape of laser spots.

The defocusing will influence the negative appearance of banding; especially during the illumination of HDI (High Definition Images). Such type of the writing head was built in the first electrophotographic machines of the type HP Indigo series 1000, which were replaced by greater and quicker models of the series 5000. In this series 4-beam array arrangement of laser diodes was replaced with 12 beam array arrangement (Livne & Plotkin, 2003).

3. Experimental part

In this work we analyzed influence of the laser diode power change on multicolor reproduction. This means that we focused us on final print on the standard fine art paper. For our analysis we created special printing form which included standard CMYK RGB wedge in steps of 10 % screen value, ISO standard illustration and 378 fields for production of ICC profile.

Experimental prints were made on previously calibrated electrophotographic machine HP Indigo TurboStream after which the power variation of the laser head was performed with other electrophotography parameters retaining constant.
For colorimetric measurements we applied spectrophotometers X-rite DTP 41 and X-rite Swatch Book which use MONACO version Platinum (3D gamut) and ColorShop (determination of ΔE CIE Lab) software.

Two calibration areas (solid tone and 50% screen value) were thoroughly analyzed for colorimetric purpose. In addition, shape and dimensions of the screen dot was tested with Image Analysis (Personal IAS) apparatus, i.e. printing elements were analyzed in characteristic tone values to evaluate dot gain. The results are presented in three dimensional and two dimensional forms for the primaries (CMY) and for the secondary colors (RGB). (Majnaric et al.,2007.)

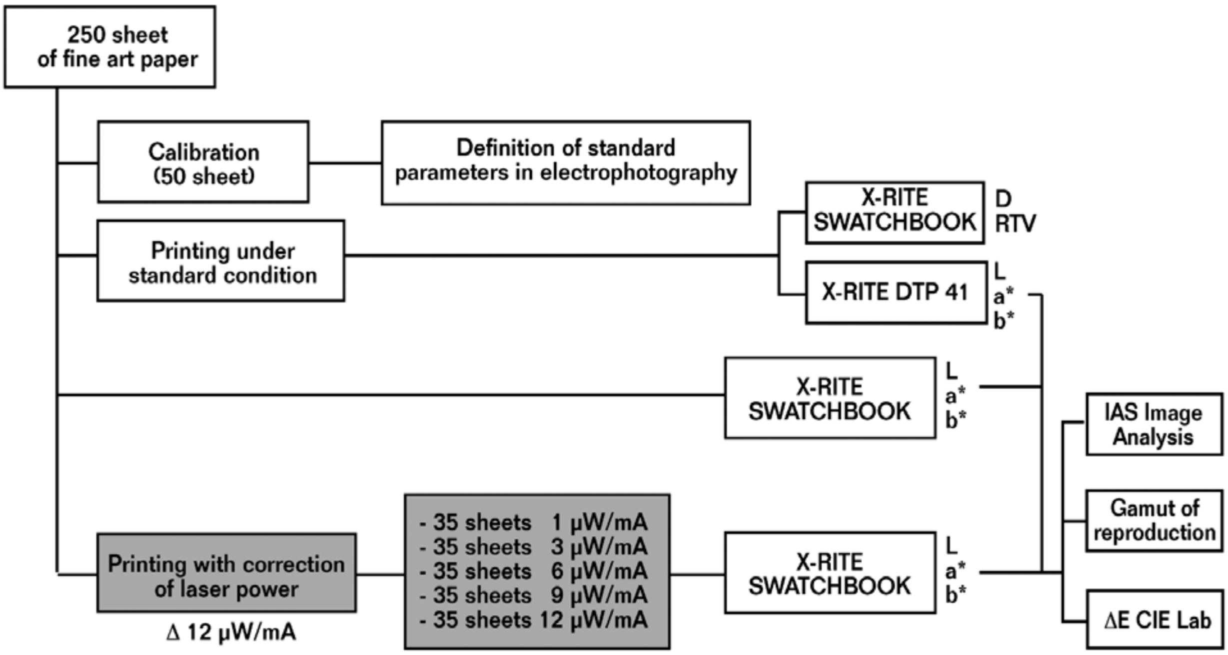


Fig. 3. Schematic presentation of the performed experiment with the presentation of parameters after calibration

4. Results and discussion

Spectrophotometric results obtained by power variation of the laser source are presented in figures 4,5 and 6. The results are expressed in the form of space gamut for several laser powers (1 μW/mA, 6 μW/mA, 12 μW/mA), as well as the color difference CIE LAB ΔE for characteristic colors (CMYK RGB). We designate laser powers values with numbers representing applied laser powers (e.g. laser 6 = laser operates in 6 μW/mA regime).

Induced laser power amplification generates maximal increment (ΔV) of 10,704 gamut space V volume units when printed on fine art paper. Measured peak gamut space volume is realized with the laser 6 (V=762,126), while the smallest space volume is achieved with the laser 1 (V=751,422), while further increase of strength beyond 6 μW/mA (e.g. from laser 6 to laser 12) results in negligible gamut fall of 0,433 space units.

For determination of laser strength influence on print quality it is important to measure primary and process colors (cyan, magenta, yellow, red, green and violet blue) with X-rite DTP41 spectrometer on printed model. Each primary color will be presented with two characteristic patches (solid tone and 50% screen patch). Their deviation from calibration print, i.e. their color difference (CIE Lab ΔE_{2000}) which is result of variation laser strength is presented in figures 5 and 6.

Variation of the laser strength generates the visible hue deviation when printed on the fine art paper, (average coloring of all the tones is $\Delta E_{MAX} - \Delta E_{MIN} = 2,15$). For all applied laser powers solid tones, reproduced on fine art paper, reveals tone deviation ($\Delta E_{MAX} - \Delta E_{MIN} = 0{,}5335$) which could be observed measuring with optical spectrometer.

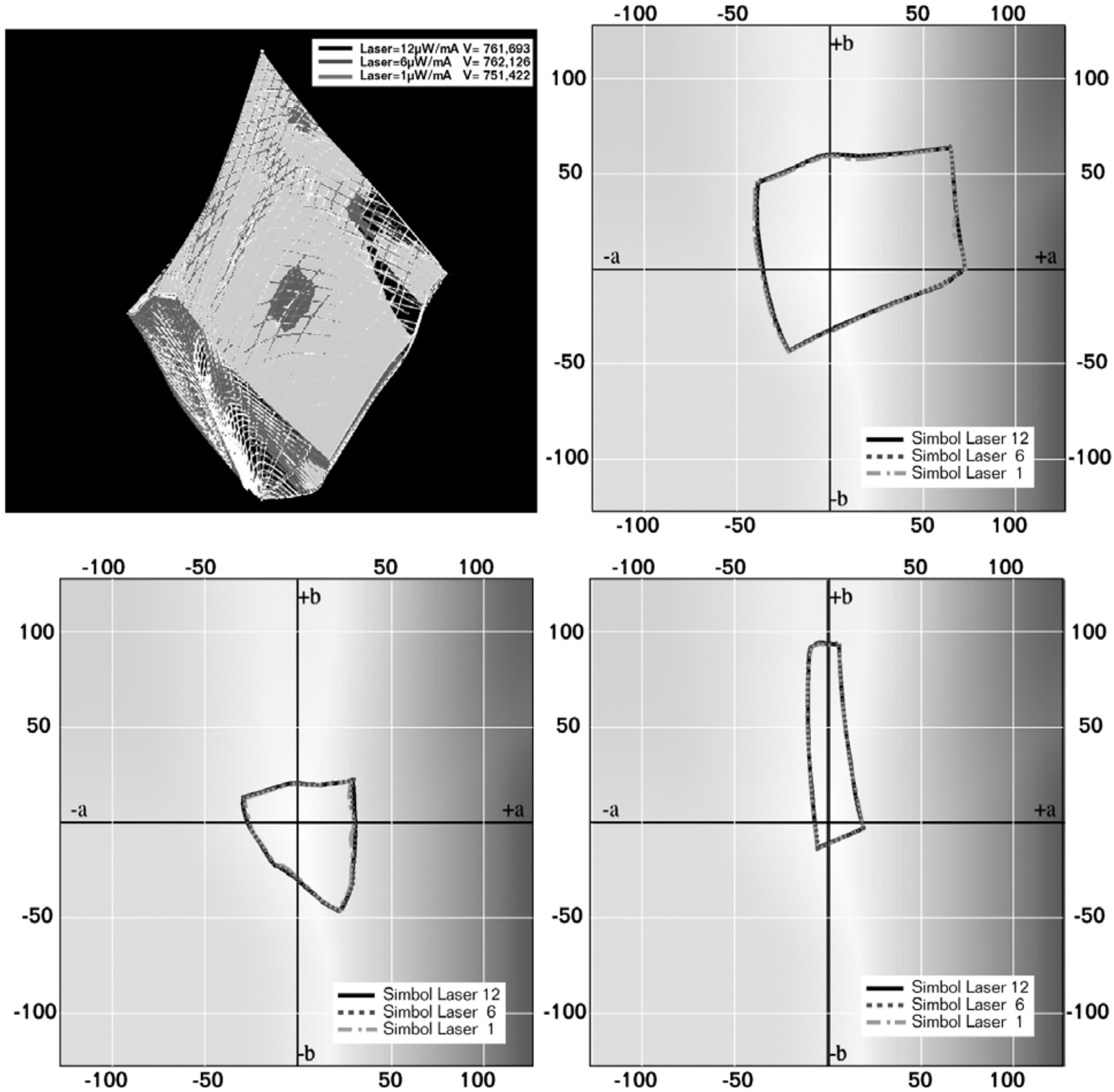


Fig. 4. Three dimensional presentation of gamut with 3 characteristic cross-sections (L=20, L=50, L=80)

This is most evident on black ($\Delta E_{100\%} = 0{,}851$) and cyan prints ($\Delta E_{100\%} = 0{,}6648$). The average deviation of the screened hue colors is most prominent on black print ($\Delta E_{50\%} = 5{,}0560$), yellow print ($\Delta E_{50\%} = 4{,}1847$), while magenta print exhibits value ($\Delta E_{50\%} = 2{,}4199$) and cyan print ($\Delta E_{50\%} = 2{,}2207$). This behavior influences the maximum color difference in green prints ($\Delta E_{50\%} = 5{,}5947$) and red prints ($\Delta E_{50\%} = 3{,}5644$) which is result of colour mixing of process colors (CMY). In respect to the calibration the smallest aberration appears with the strength application of the laser 9 (cyan and magenta) and laser 1 (yellow).

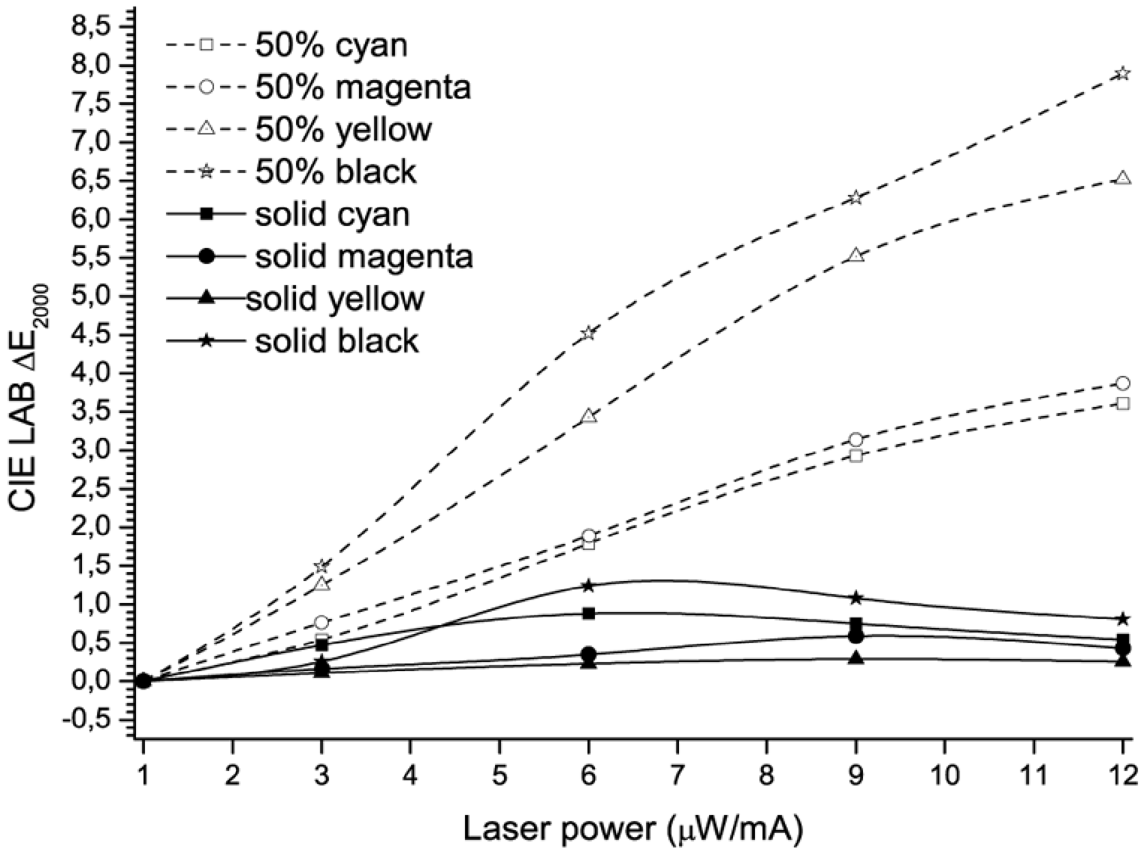


Fig. 5. CIE LAB ΔE color differences for cyan, magenta and yellow

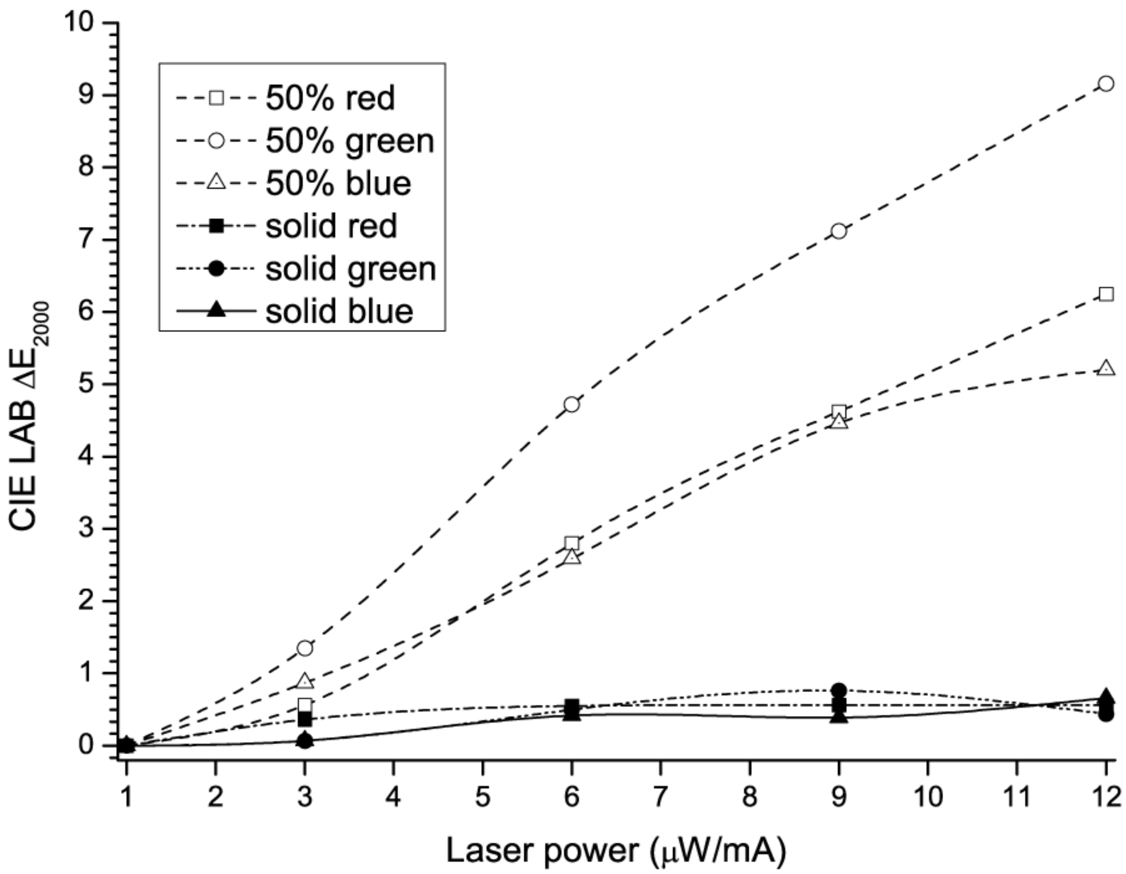


Fig. 6. CIE LAB ΔE color differences for red, green and violet blue

It was compared with visual estimation which presents colors shift regarded to the calibration print. Fine quality reproduction of the secondary color prints depends on laser powers. Our results point that optimum choice should be laser 8 for violet blue, laser 2 for green and laser 1 for red.

Combination of high voltage of scorotron net (-850V) applied on photoconductor drum to charge it on uniform potential and the strength of laser power (laser strength 12) to selectively discharge preset areas on photoconductor produces an electrostatic latent image (potential difference) of the original document on the surface of drum.

The voltage difference between illuminated and non illuminated areas is approximately 600V. In this way the latent printing form is formed which can accept the optimal quantity of developer material (100% of color coating on print corresponds to standard classical lithographic offset printing).

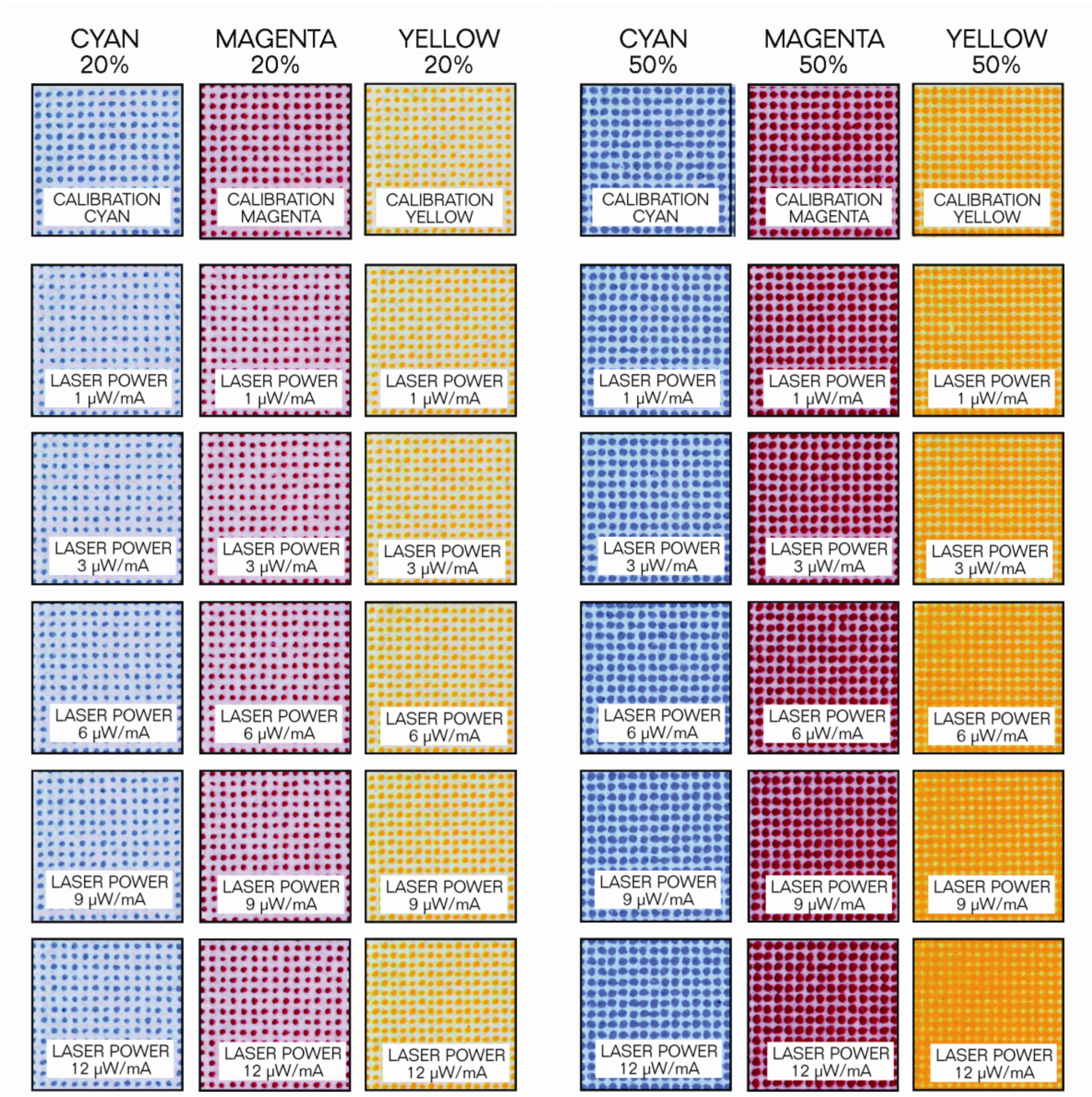


Fig. 7. View of the CMY segment of prints in the screen area of 20% and 50%

Regulation of the scorotrone voltage and the laser source strength enables to change the voltage of photoconductor, i.e. to influence the total ink quantity on photoconductor (future print).

By lowering the voltage difference it is possible to generate the intermediate tones. It was noticed, on the tested printing substrate, that the change of the laser strength influences the minimal deviation in coloring the solid tones (100% saturated inks). Laser power will influence the change of the printed screen value (mostly on black and yellow, followed by green and red). Increase of laser source power generates dimensional enlargement of the screen elements which is presented in fig. 7 and 8.

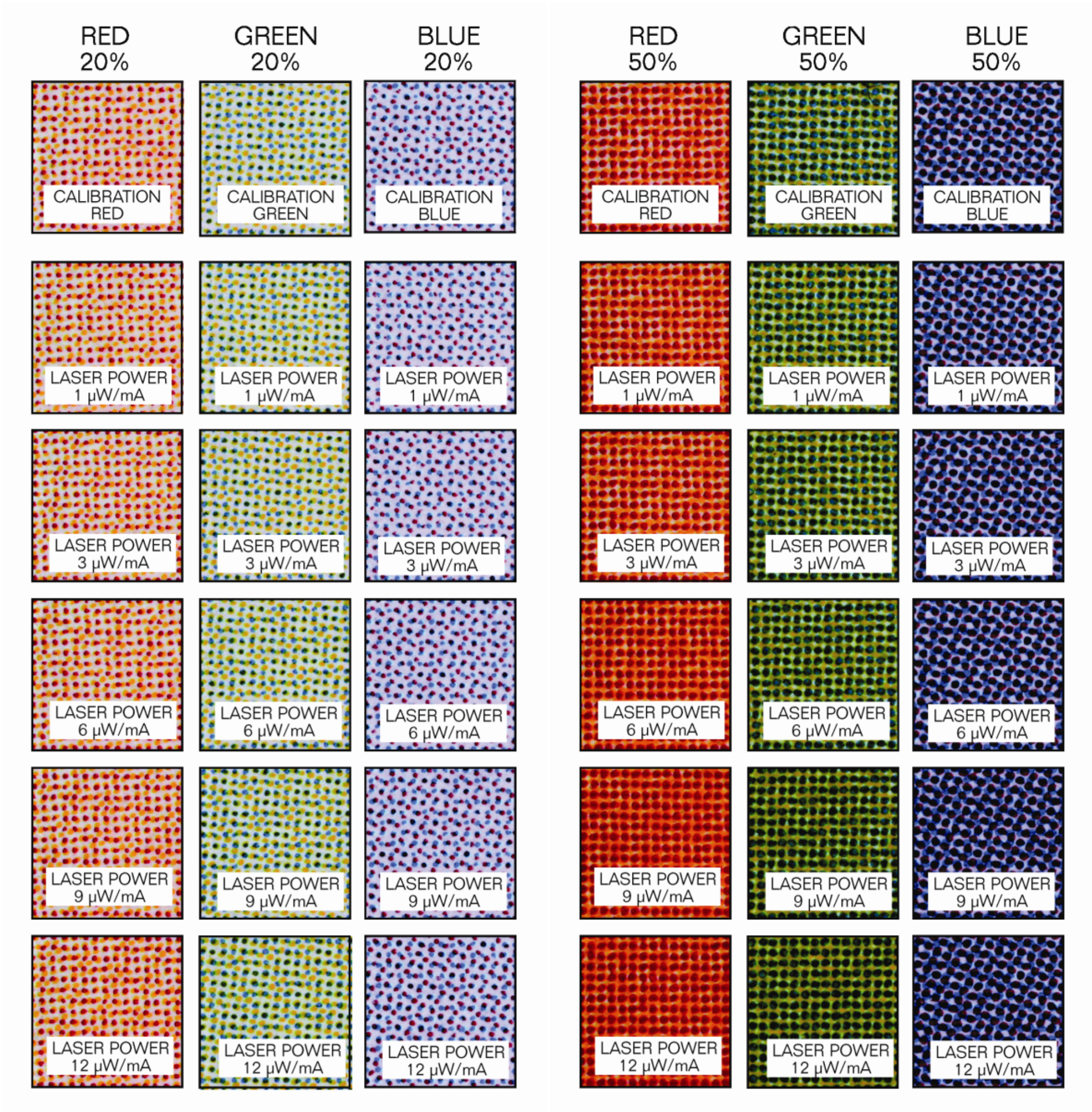


Fig. 8. View of the RGB segment of prints in the screen area of 20% and 50%

With the image analysis device it is possible to measure precisely the reproduced size of each printing element (screen dot), as well as its geometrical exactness (roundness). Figure 9 presents the dependence of the laser strength on the average size of the screen element (Fleming et al., 2003).

As a result of the laser strength increase the screen elements have proportional diameter size increase. This increase is smaller for lighter tones (20% screen value) compared to the darker tones (50% screen value).

Cyan, magenta and black have considerably smaller increase compared to yellow ($\Delta d_{cyan20\%}$= 12,5 µm, $\Delta d_{magenta20\%}$= 12,5 µm, $\Delta d_{yellow20\%}$= 11,06 µm, $\Delta d_{black20\%}$= 13,78 µm). Depending on coloring, the deviations of the screen element diameter are more expressed ($\Delta d_{cyan50\%}$= 10,15 µm, $\Delta d_{magenta50\%}$= 16,51 µm, $\Delta d_{black50\%}$= 16,98 µm) in medium tone values (50% screen value) due to the laser influence.

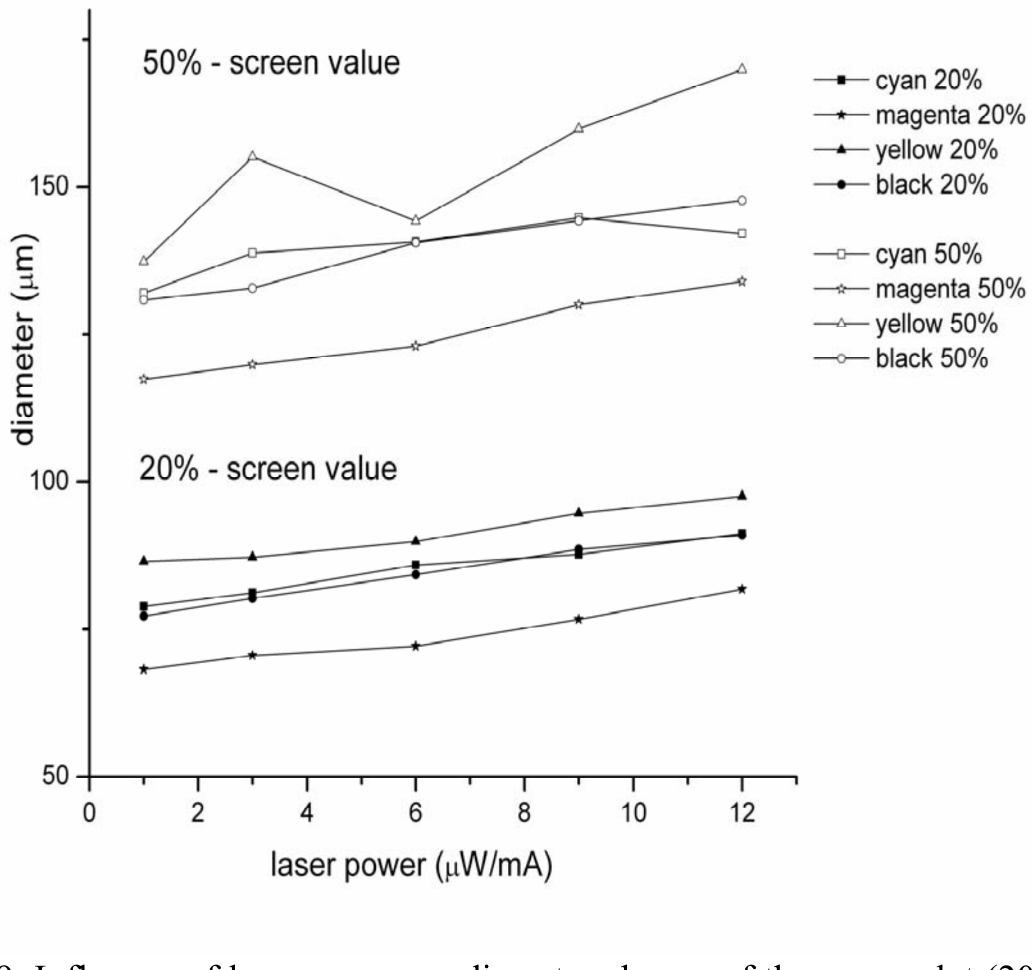
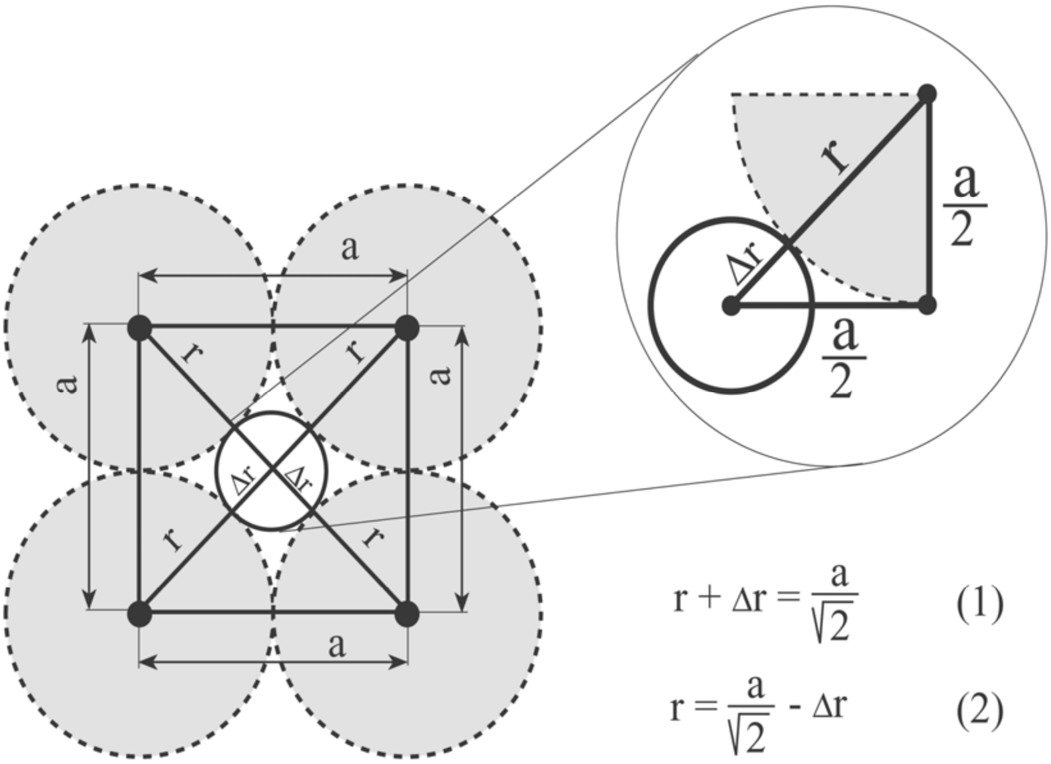


Fig. 9. Influence of laser power on diameter change of the screen dot (20% and 50% screen values). Presented results are mean values of measured screen dots dimensions on area of 6 mm^2

On the printed 50% yellow print, laser strength higher than 6 µW/mA will influence the partial overlap of screen elements. In case of overlapping elements it was not possible to distinguish dark dots and the measuring device starts to recognize remind space between dots as a new white "dot". Mathematic correlation of the light and the dark dot is given in figure 10. Concentration of the yellow pigment in liquid ElectroInk (special electrophotographic liquid toner for Digital Color Offset) is higher compared to other ElectroInks (cyan, magenta and black). Increase of pigment particles portion in liquid toner will require increase of electric conductivity of ElectroInk, which directly depends on the quality of the ink adherence on photoconductor.(Leach & Pierce, 1999.)



$$r + \Delta r = \frac{a}{\sqrt{2}} \qquad (1)$$

$$r = \frac{a}{\sqrt{2}} - \Delta r \qquad (2)$$

a = distance between two objects (print dot)
r = average diameter of print (dark) dot
Δr = avarage diameter white dot (surface without ink)

Fig. 10. Illustration for mathematical expression used for calculating actual average diameter of printed overlapped dark dot from measured white "dot"

Excessive fraction of this substances results in thicker ink layers and enhanced dot gain, which is predominantly observable for higher tone values. Ideally reproduced circular screen elements have theoretically the circularity value = 1. In our experiment three of four primary colors (CYK) exhibits the same relative gain value (0,02 units) of the total circularity change.

The maximal geometrical deviation of the screen elements (dots) was noticed for yellow color (1,19), followed by cyan (1,18) and black (1,07). Deviation from this behavior shows magenta with increase of circularity by approximately 2%. Reason for this behavior lays in the fact that magenta liquid toner has minimal electroconductivity (85 pmho/cm^2).

Such electroconductivity requires bigger potential difference on photoconductor. By increasing the laser strength, the roundness of the reproduced elements decreases minimally (the printing elements loose roundness).

Increasing of laser power generates larger screen dot for ink with higher density. It is even more evident on the reproduced secondary screened tones (red, green, violet blue).

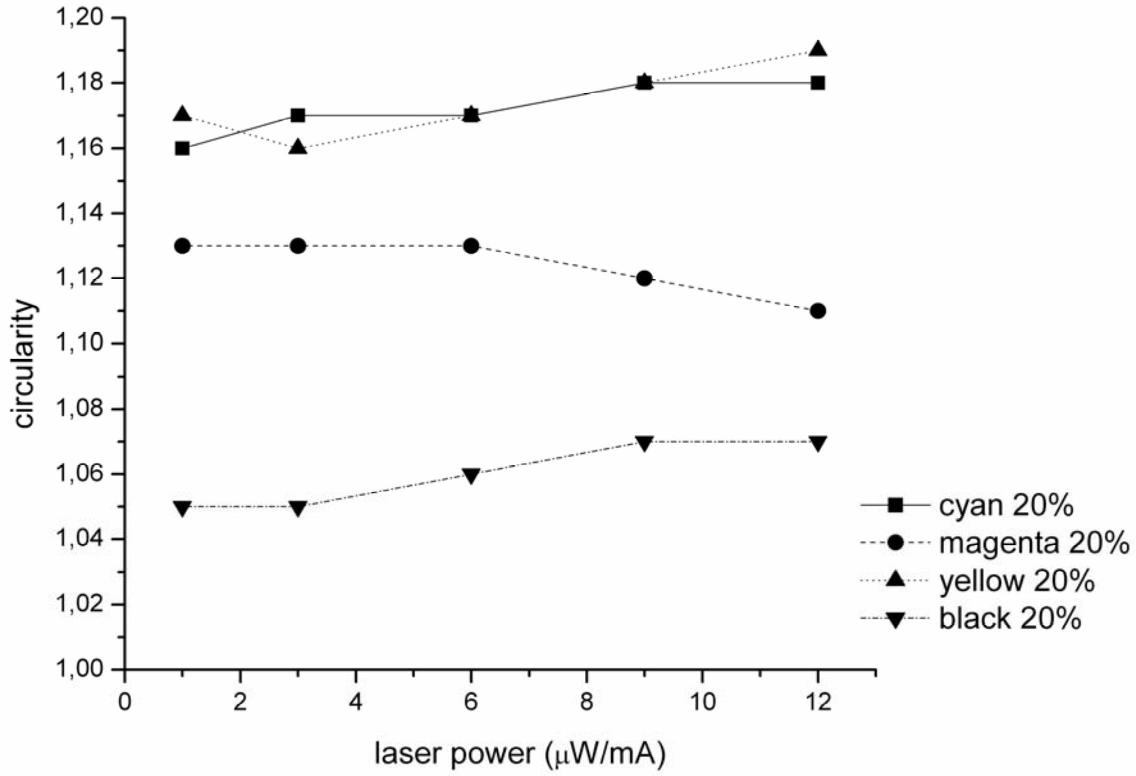


Fig. 11. Circularity of printed element as a function of laser power for 20% screen value

5. Conclusion

Experiments were conducted to ascertain the relationships between hues (subject to the constraint of equal lightness and chroma) and laser power. The null hypothesis was that it is possible to vary size of screen dot (indirectly - hue) by means of varying laser power which was not yet experimentally confirmed. Influence of laser power increase on geometrical deformation was also investigated. The experimental data demonstrate consistent support to this hypothesis.

The printed light and middle tones formed by varying the laser power in above mentioned process suffer ten times greater tone change compared to the solid patches. This resulted in minimal change in gamut. The largest gamut surface appears by the activation of the laser power of 6 μW/mA.

By comparing the calibrated images and the images obtained with laser power regulation (from 1 to 12 μW/mA), it was noticeable that the process inks in solid patch had the minimal change (ΔE_{black}=0,851, ΔE_{cyan}=0,6648, $\Delta E_{magenta}$= 0,3889, ΔE_{yellow}=0,2296).

It is similar with the secondary inks in solid patch ΔE_{red}=0,5116, ΔE_{green}=0,4483, ΔE_{blue}=0,3920). In the screen reproduction (50% screen value) stronger influence of laser strength on the reproduction is noticeable ((ΔE_{cyan}=2,2207; $\Delta E_{magenta}$=2,4199; ΔE_{yellow}=4,1847, ΔE_{black}=5,0560; ΔE_{red}=3,5644; ΔE_{green}=5,5947; ΔE_{blue}=3,2833).

These results demonstrate our initial idea that we could initiate change of screen value by means of laser power change. Yet, this method must be applied selectively for every color either process or secondary.

Frequent exposure of photoreceptor with pulsed laser light generates "ageing" of charge generation layer in photoreceptor which influence on decrease of initial potential difference between printed and non-printed areas. Additional attention must be paid on yellow prints which are troublesome in sense of reproduction due to the reasons mentioned above.

For this reason yellow separation demands decrease of laser power which complicate print quality maintenance. This leads to certain screen printing defects due to mechanical damage of photoconductor surface which can be solved with regular replacement of photoreceptor with new one.

This effect can be compensated with increasing of laser power which is applied in calibration process – generation and maintenance of exact (desired) middle and low hues. By varying the input power of LED laser source the greatest change in the lighter tone values (20% Screen dot) was noticed between the black and yellow impression (diameter - d= 2,72 μm). In the medium tone values this difference was noticed between the yellow and cyan impression (d=22,35 μm).

Laser strength variation insignificantly influences the change of geometry of the printed screen elements in lighter tone domain (total change of the roundness is 0,02). By increasing the diameter of the screen elements the roundness does not decrease. The best roundness was noticed in black image which is followed by magenta, cyan and yellow.

However, there are an indication that increases of roundness is correlated with ink density and further studies need to be carried out to investigate this. A weakness of the study is that at one point we were forced (due to the screen dot overlap) to calculate dimension of printed screen dot which was approximated with simple model. Nevertheless such approach gives useful results.

In this paper impact of laser power on creation of halftones in color reproduction was investigated. The results given were for printing substrates of finest quality (fine art papers). In future research the impact of writing head laser power on color reproduction will be investigated on lower quality substrates (uncoated and recycled paper). Poor optical and mechanical properties are expected to generate lower quality reproduction of screen elements and blurred prints.

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