12. Savjetovanje o materijalima, tehnologijama, trenju i trošenju
12. Conference on Materials, Processes, Friction and Wear
MATRIB'07, Vela Luka, 21-23.06.2007.

THE INFLUENCE OF ELECTROPHOTOGRAPHIC DIODE LASER ON DURABILITY OF ORGANIC PHOTOCONDUCTORS

UTJECAJ ELEKTROFOTOGRAFSKOG DIODNOG LASERA NA TRAJNOST ORGANSKIH FOTOKONDUKTORA

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Izvorni znanstveni rad / Original scientific paper

Abstract: Electrophotography is one of the most complex printing techniques. Elektrophotographic machines apply 5 basic phases in their work and they are synchronized repeated. They are corona charging, photoconductor exposition, photoconductor developing, ink transfer and photoconductor cleaning. The basis of the whole process is the organic semiconductor (photoreceptor), on which the virtual printing form for each impression is formed by exposition. Organic semiconductor looses its electric conductivity by numerous expositions which result in weaker adherence of toner to photoconductor. Except the mechanical wearing this is the main cause of quality loss of the final impression. This work gives the answer on how extremely great number of IR laser expositions influence the photoreceptor, and how such oscillations appear on a print. The photoconductor analysis lasted for 7 weeks, in which 131806 imaging (prints) were made. For determining the reproduction quality the densitometric measuring method has been applied (based on reflection from the printed substrate) as well as the spectrophotometric measuring methods (based on defining the impression inking).
Key words: electrophotographic printing, fotoconductor durability, spectrophotometry

Sažetak: Elektrofotografija je jedna od najsloženijih tiskarskih tehnika. Elektrofotografski strojevi pri svom radu primjenjuju 5 osnovnih faza koje se sinkronizirano ponavljaju. To su: korona nabijanje, fotokonduktorsko osvjetljavanje, fotokonduktorsko razvijanje, transfer bojila i čišćenje fotokonduktora.Osnova cijelog procesa je organski poluvodič (fotoreceptor) na kojemu se za svaki otisak osvjetljavanjem formira virtualna tiskovna forma. Organski poluvodički sloj gubi mnogobrojnim osvjetljavanjem svoju električnu provodljivost, što će dugoročno rezultirati slabijim prihvaćanjem tonera za fotokonduktor. Uz mehaničko trošenje to je i glavni uzrok gubitka kvalitete konačnog otiska. U ovom radu dan je odgovor na to kako ekstremno velik broj IR laserskih osvjetljavanja utječe na fotoreceptor, te kakve oscilacije nastaju na otisku. Analiza fotokonduktora trajala je 7 tjedana, pri čemu je izvršeno 131806 oslikavanja (otiskivanja). Za određivanje kvalitete reprodukcije primijenjene su denzitometriske metode mjerenja (bazirane na reflektanciji s otisnute podloge) i spektrofotometrijske metode mjerenja (bazirane na definiranju obojenja otiska).
Ključne riječi: elektrofotografski tisak, trajnost fotokonduktora, spektrofotometrija

1. Introduction

The basic principle of electrophotographic printing is based on semiconductor photoconductors. In electrophotographic printing, it is necessary to form the virtual printing form on photoconductor, which will be renewedly formed with each rotation cycle. In this way the printing of commercially unprofitable small runs as well as personalizing printing is possible (1).

For creating the virtual printing form, it is necessary to expose the photoconductor to the activity of two devices. They are scorotrone (the device for permanent charging the photoconductor surface) and the laser head (the device which selectively illuminates the photoconductor surface). During the activity of the laser source, the photoconductor will change the previously formed electric potential, forming the strong electrostatic field which will selectively accept the colour toner particles. Depending on the principle of photoconductor surface charging, the following expositions can be distinguished: the negative exposition (CAD = Charged Area Development) and the positive one (DAD = Discharged Area Development). This work analyses DAD electrophotographic principle of illumination which is based on OPC (Organic Photo Conductor) photoconductor and IR illumination (created by means of diode laser source λ=830 nm).(2)

2. Theoretical part

2.1. OPC Photoconductors

The composition of OPC (Organic PhotoConductor) photoconductor is very complicated and consists of 5 very thin layers. They are the basic aluminium drum, permanently positively charged basic electrode, the layer with the formed charge, the layer for the charge transport and the negative charged surface (figure 1). For generating the virtual printing form the layer with the formed charge and the thickness of 2 μm which can be composed of H_2Pc, TiOPc and Azo-Pigment (3) has an important role.

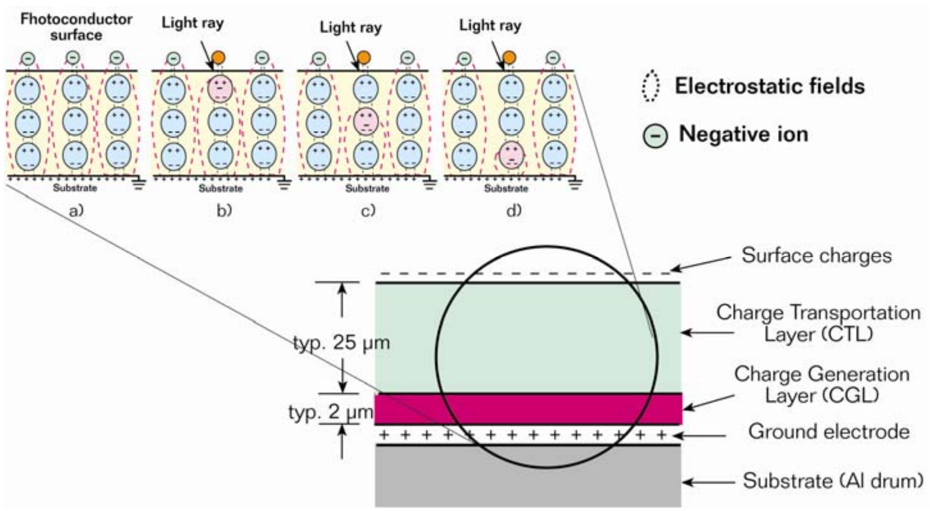

Figure 1. OPC photoconductor and its principle of positive illumination

In the starting phase of DAD electrophotographic printing, the surface of OPC photoconductor is exposed to a very strong negative charge of corona. During the charging process the corona will constantly emit the negative charge carriers, which will finish at the surface of photoconductor. For the formation of the constant surface negative charge, much credit goes to the scorotrone net, which is directly linked with the negative charging source. The formation of negative ion emission is regulated by the direct charge. The scorotrone activity in the central layer of photoconductor creates the strong electrostatic field in which the electrons move freely within their own molecules (figure 1a). In this way the future non printing areas are formed.

In the second phase of electrophotographic process, photoconductor is selectively illuminated with the laser IR light (λ=830 nm). In the moment of selective illumination of photoconductor drum (printing elements), the electrons move from the negatively charged surface in the direction of highly polarized molecule of the central semiconductor layer, which starts the reduction of the negative surface charge of photoconductor. The molecule which accepted the free electron becomes an ion (the molecule nearest the surface) in which the shift of electrostatic field appears. The electrostatic field moves down into the lower layer and exists now between the negatively charged molecule and the positively charged basic electrode (figure 1b). Electrons in the ion influence the strong electrostatic field, causing the migration of electrons to the lower semiconductor molecule. By obtaining the electrons, such molecules becomes the ion in which the surface negative charge further decreases (neutralizes) (figure 1c).

The migration of the negative charge repeats from the higher to the lower molecules, i.e. up to the last molecule which limits with the layer for charge formation. In this moment the free electron in ion is attracted by the positive basic electrode which neutralizes ions and the positive basis (figure 1d). Such illumination process is instantaneous. The movement of electrons from the photoconductor surface in the direction of the basis lasts during the illumination of the photoconductor surface. The emission of electrons stops after the stopping of illumination. At longer light exposition the total surface charge of photoconductor will be decreased, i.e. very low negative charge will be formed on the surface of the photoconductor (4).

The final illumination result is the virtual printing form which has the non printing areas (the surface more negative potential – 600V) and the printing elements (the exposed positive potential – 100 V). The obtained potential difference of – 500 V will enable the selective adherence of the negatively charged ink, i.e. the inking of more positive printing elements. Continuous laser illumination of the photoconductor surface will influence the crystalline structure of the semiconductor layer which results in the fall of the potential difference among the non printing areas and the printing elements. Smaller potential difference will result in weaker adherence of the negative toner, i.e. with the decrease of the reproduction quality.

2.2. Evaluation of the printing quality

The quality of the printing technique is based on the alignment of the obtained prints, i.e. the smaller oscillations of the ink layer on paper are, the greater the printing quality is. Direct measurement of the ink coating on paper is very complicated, so the layer of the printing ink on paper is indirectly controlled by the densitometric and spectrophotometric devices.

Densitometric devices base their work on measuring reflectance (β) from the white substrate (L_{ew}) and the printed surface (L_{ep}), through the standardized filters. The colour density (D) is the logarithmic value of the ratio of the printed layer with the ink and the reflected white light from the printing substrate (5).

$$D = \log \frac{1}{\beta} \qquad \beta = \frac{L_{ep}}{L_{ew}}$$

D = Ink density value
β = Reflactance factor
L_{ep} = Light reflectance of the printing ink
L_{ew} = Light reflectance of the reference white

Three stimulus values XYZ which correspond to the human colour perception of ink (defined by hue, saturation and brightness) are given by the spectrophotometers as the output value. Three stimulus values are possible to be presented graphically in different colour spaces, the most often used of which is CIE Lab. Each colour is described by three value (L*a*b*) in which L* defines the tone brightness, while a* and b* present the chromatic value. For comparison of two different colours the formula for calculation the colour difference ΔE is used. The last variant dates from the year 2000 (CIE LAB ΔE_{2000}). (6)

$$\Delta L^* = L^*_{act} - L^*_{ref}$$
$$\Delta a^* = a^*_{act} - a^*_{ref}$$
$$\Delta b^* = b^*_{act} - b^*_{ref}$$
$$\Delta E^*_{ab} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

I.	ΔE between 0 i 1	= deviation cannot be perceived
II.	ΔE between 1 i 2	= very small deviation
III.	ΔE between 2 i 3,5	= medium deviation
IV.	ΔE between 3,5 i 5	= large deviation
V	ΔE exceeding 5	= massive deviation

$$\Delta E^*_{2000} = \sqrt{\left(\frac{\Delta L'}{S_L k_L}\right)^2 + \left(\frac{\Delta C'}{S_C k_C}\right)^2 + \left(\frac{\Delta H'}{S_H k_H}\right)^2 + R_T\left(\frac{\Delta C'}{S_C k_C}\right)\left(\frac{\Delta H'}{S_H k_H}\right)}$$

$$S_L = 1 + \frac{0{,}015\,(\bar{L}' - 50)^2}{\sqrt{20 + (\bar{L}' - 50)^2}} \qquad S_C = 1 + 0{,}045\,\bar{C}' \qquad S_H = 1 + 0{,}015\,\bar{C}'T$$

$$T = 1 - 0{,}17\cos(h' - 30^\circ) + 0{,}24\cos(2h') + 0{,}32\cos(3h' + 6^\circ) - 0{,}20\cos(4h' - 63^\circ) \qquad R_T = -\sin(2\Delta\Theta)\,R_c$$

$$\Delta\Theta = 30\exp\{-[(h' - 275^\circ)/25]^2\} \qquad R_c = 2\sqrt{\frac{\bar{C}'^7}{\bar{C}'^7 + 25^7}}$$

3. Experimental part

For controlling the problems of the electrophotographic photoconductor wearing, the electrophotographic printing machine HP Indigo TurboStream was used. Its basic characteristics are presented in table 1. For investigation the photoconductor state the printing form was created which contained the classical printing element for reproduction quality control (step-like CMYK wedges and standard achromatic and chromatic illustrations). The photoconductor wearing happened from 17th October to 19th December in 2005, during which time 131806 illuminations were made (figure 2).Immediately before each experimental printing the calibration of the machine was performed, which was successfully done.

The state of the photoconductor during the investigation is presented by indirect method, i.e. by the print quality analysis. For determination of the photoconductor state the fine art paper was used (Simbol 150 g/m^2). By the Densitometric analysis, the curves (D/SV) were constructed, i.e. the colour differences ΔE CIE Lab. were calculated by the spectrophotometric analysis

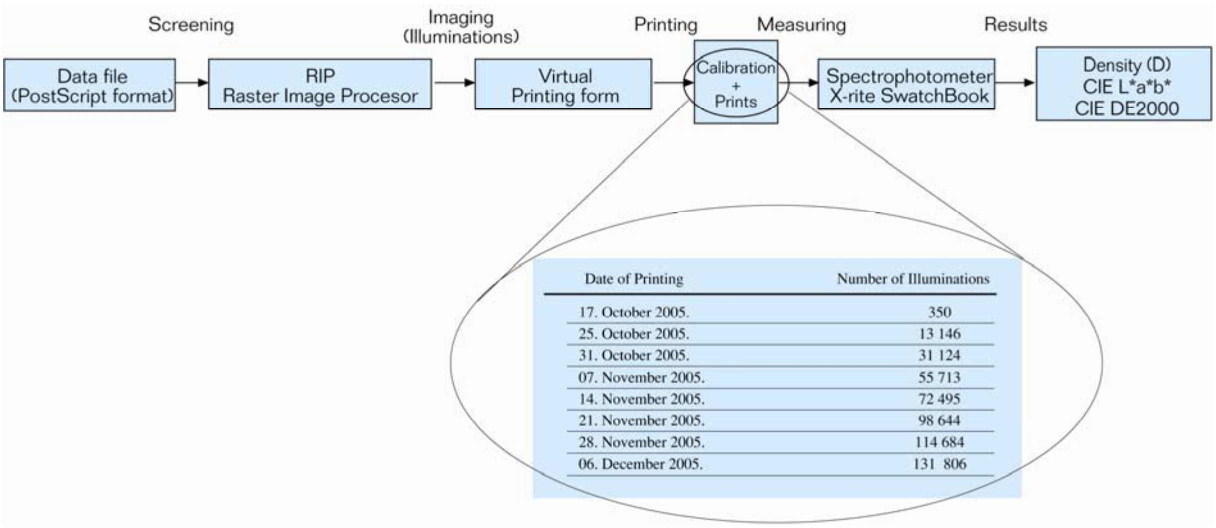

Figure 2. Presentation of the investigation with the terms of the photoconductor investigations

Table 1. Characteristics of HP Indigo TurboStream-a

Image size	max. 308 x 437 mm
Paper size	max. 320 x 464 mm
Process speed	60 cm per second
Throughput	8000 single-colour A4 size per hour
	2000 four-colour A4 size per hour
Resolution	812 dpi
Data rate	600 Mbit/sec
Input formats	Adobe PostScript, PDF
Automatic duplex printing	
Processor	Pentium III
CPU RAM	384 MB
Phisical image memory	128 MB
Image memory disk	36 GB
Network	100 Base-T
RIP	Adobe PostScript 3
Peripherals	15” monitor
	CD-ROM
	Floppy drive
	JAZ drive
Options	Automatic duplex
	Electronic collation
	Yours Truly Personalisation
	High Definition Imaging (HDI)

4. Investigation results and discussion

Voltage oscillations on photoconductor can be indirectly controlled by observing the quality of the produced prints. Densitometric method (Reflectance measurements of the printed inks on the printing substrate) is very often in graphic industry. In figure 3 the graphs of colour density dependence (D) on screen value are presented for four process inks (CMYK).

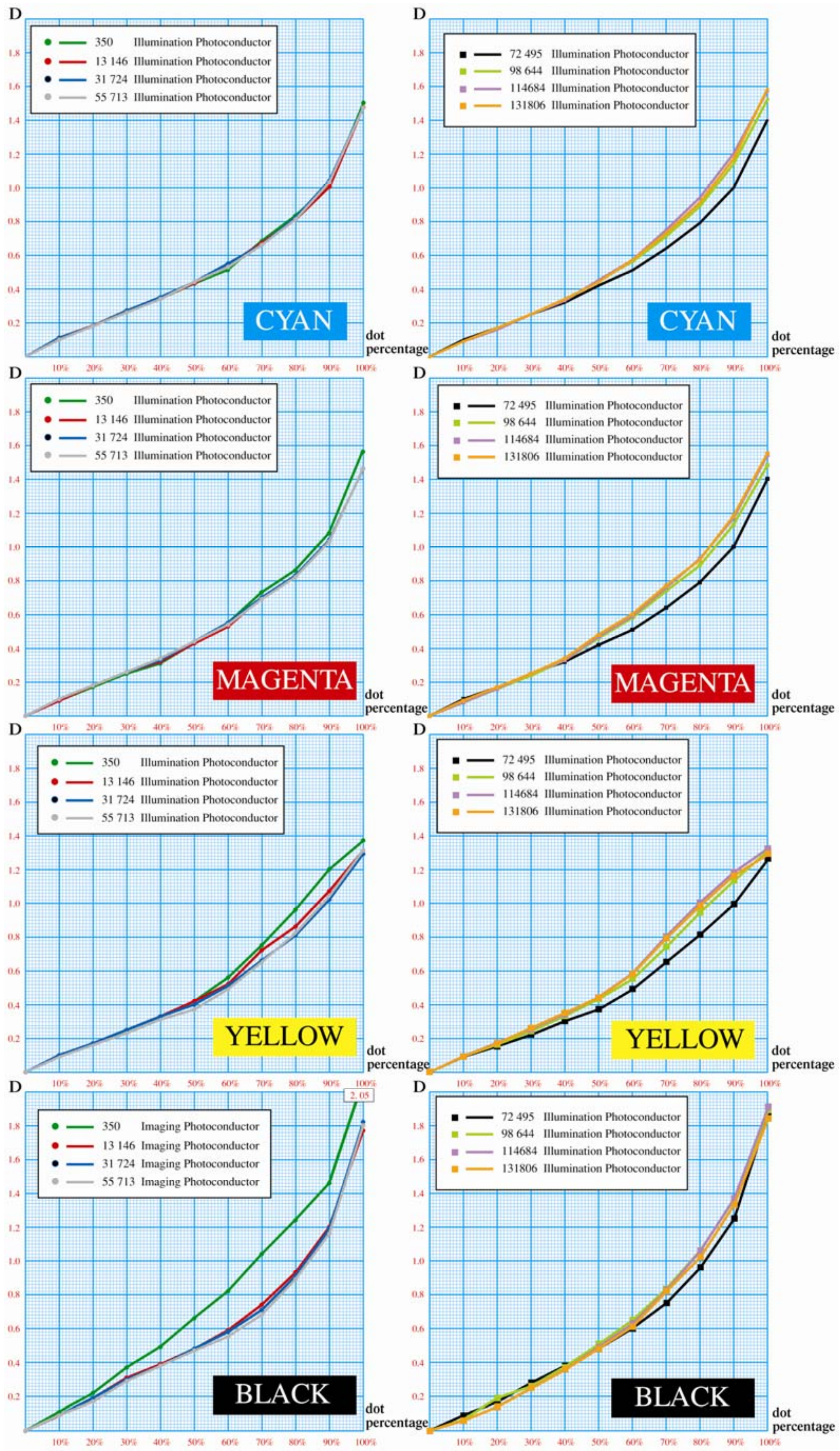

Figure 3. Relationship of the color density of the screen elements on the number of illuminations of the photoconductor fro CMYK colours

In reproduction of cyan, it is visible that all the curves up to 72 495 illuminations are completely aligned: which follows by the increase of the colour density in darker tone values (from 60% SV to 100% SV).
In the reproduction pf magenta, during the prolonged illumination, there is no greater deviation in colour density observed. However, it was noticed that during the starting experimental investigations the decrease of colour density appears, which is increased after the 72495 illuminations. These changes are most visible in the area of 50 to 100% SV.
Yellow colour shows the constant oscillation in colour density in darker tones during the greater number of illuminations. The same as in magenta, the starting colour decrease in darker tones was observed (50% - 100% SV), but after four weeks of printing (72 495) the increase of the colour density appears in these areas.

The dependence of the colour density of black prints on the number of illuminations is very similar to previopusly mentioned inks. The only difference is in the starting curve (350 illuminations) which is printed with greater ink layer which results in greater colour density (D_{max}=2,05).
Such changes in colour density (decrease and increase) are the result of the previous calibration processes during which the voltage correction of the printing elements and the non printing areas on the photoconductor surface appear. For the achieving of the start potential difference (of -500V) the intensity of laser emission (laser strength) will have to be increased. After 72495 illuminations the laser strength is set to maximum, and the ink coating is regulated in further calibration process by voltage variations of the developing drum. This has a consequence greater toner flow, i.e. greater colour density of darker tones.

Spectrophotometric analysis gives more precise results on differences in colour tones and in this way it is more suitable for the control of the photoconductor state. Colour difference ΔE_{00} between the standard offset print and the experimental CMYK prints in the areas of 10%, 50% i 90% SV are presented in figure 4.

In cyan prints the brighter screen areas (10% SV) constantly increase with the increase of the illumination number. The colour difference (ΔE_{131860}- ΔE_{350}) appears from 1,24. During the illuminations, the middle and the dark areas (50% and 90% SV) behave identically. The only difference in cyan is visible in the curves of 90% screen which are nearer the prints of the standard offset. During 72495 illuminations in these areas the greatest change in colour appears (50% SV ΔE_{72495}- ΔE_{350}=0,65 i.e. 90% SV ΔE_{72495}- ΔE_{350} = 0,92). After the 72495 illumination the fall of ΔE appears up to 98 644 illuminations (for 90% SV, ΔE_{min}=1,37), that is 131806 illuminations (for 50% SV, ΔE_{min}=2,96).

During the first 72 495 illuminations, on the brighter screen areas of the magenta prints (10% SV) smaller colour ΔE_{350}- ΔE_{72495} of 1,13 will be noticed. With further illuminations the increase in ΔE difference will appear which is the highest at 114 682 prints (ΔE_{114684}- ΔE_{72495}=1,61). With longer photoconductor illumination 50% magenta screen will constantly decrease , and the total colour deviation (ΔE_{350}- ΔE_{131806}) will be 1,53. Coloring in the area 90% SV increases up to 72 495 illuminations (ΔE_{72495}- ΔE_{350}=1,29) in which the prints become brighter. After that the fall in colour difference follows, the toner adherence on photoconductor becomes weaker, which is compensated by the developing drum. This results in the coating increase which is at 131 806 print the most similar to the print obtained by the standard offset technique (ΔE_{min}=3,95).

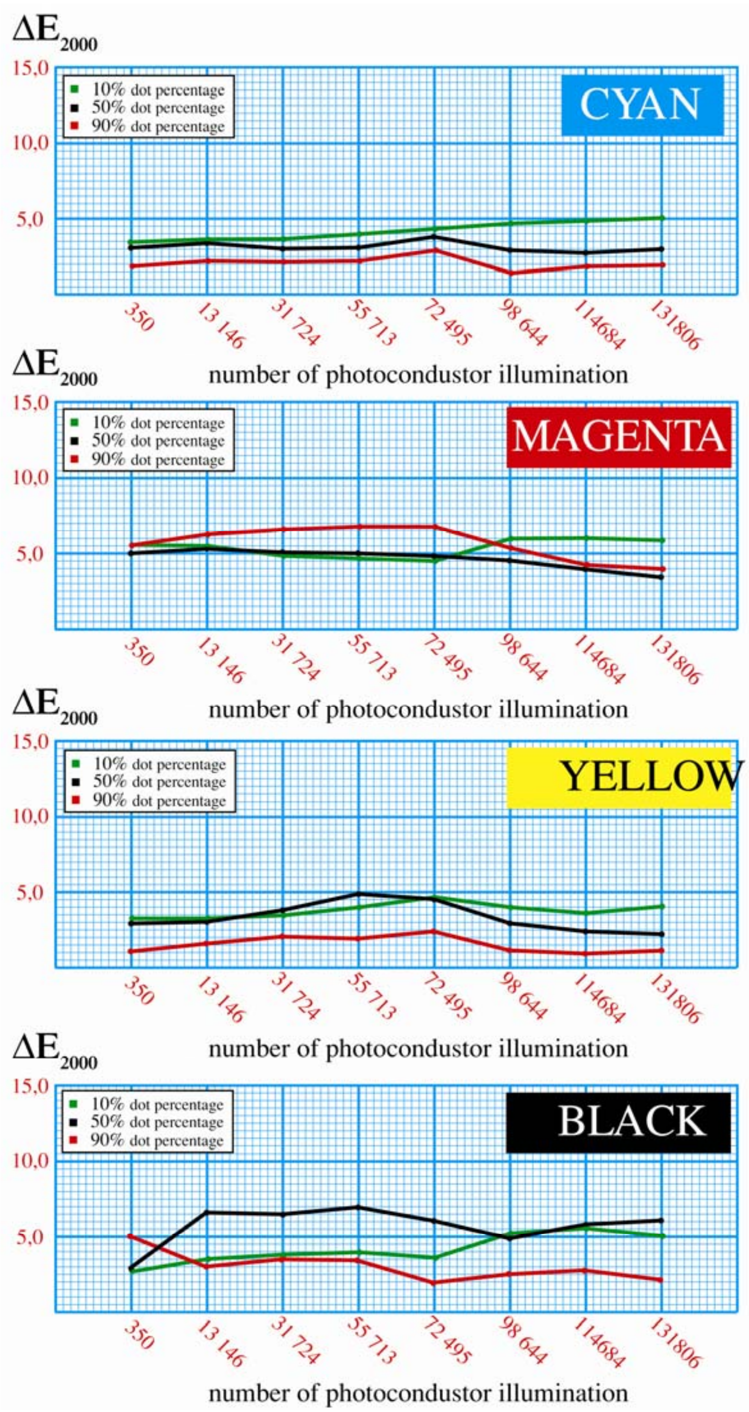

Figure 4. Colour difference ΔE_{00} caused by different number of photoconductor illumination

In the reproduction of 10% and 90% yellow, the differences in curves are not visible. Smaller difference is visible in 90% curve which is visually nearer to the ideal print of the standard offset. During 72495 illuminations, both screen yellow areas become brighter, i.e. the colour difference ΔE_{00} increases (10%SV ΔE_{72495}- ΔE_{350}=1,25 that is 90% SV ΔE_{72495}- ΔE_{350}=1,31). The fall follows after that and the prints are darker. The yellow areas in 50% screen during the experimental printing have the greatest deviation (ΔE_{max}-ΔE_{min}=2,52). In relation to the offset standard the greatest aberration appears at 55713 illuminations while the smallest one appears at 131806 illuminations. The curves of dependence ΔE_{00} on illumination of photoconductor are the most regular in yellow colour. The reason for that can be found in high electric conductivity of the yellow colour (102 pmho/scm), which enables better toner adherence to the photoconductor surface (to printing elements).

In three black analyzed screen surface the regularity in the constructed curves does not exist. During the experimental illumination, the colour difference at 90%-black screens decreases with time (ΔE_{350}-ΔE_{131806}=1,29). During the calibration the laser cannot form a great difference in potential and it is necessary to apply the regulation of the developing drum for greater colour density. Colour densities (ΔE) of the black 10% screens behave in quite opposite manner, i.e. with greater number of illumination the print becomes brighter (ΔE_{131806}-ΔE_{350}=2,30). The areas in 50% screen during the illumination have the greatest change.

During the first 13146 illuminations the greatest change in relation to the standard offset appeared (ΔE_{13146}- ΔE_{350} = 3,37). After that, the colour difference ΔE is constant with further illumination. It lasts up to 55 713 prints. The fall in the colour difference (ΔE) follows after that, which ends at the print 98 644 (ΔE_{55713}- ΔE_{98644}=2,22).

5. Conclusion

Densitometric method of the quality control of the graphic reproduction is not suitable for the analysis of light wearing of photoconductor surface. The diagnosed changes are very small and visible only in dark tones Spectrophotometric method give more precise results about ink and they can be easier compared with the formula CIE Lab ΔE_{00}.

The dependence curves ΔE on the number of illuminations are not equal for all colours and for all tonal areas. The greatest changes appear in middle and dark areas (50% and 90% screen value), while the smallest ones are in the light areas (10% screen value). For creation of darker tones, greater laser emanation strength will be needed, on which the potential difference in pohotoconductor directly depends. The printing elements formed with lower strength of laser emanation will be printed in lighter tones, that is the smaller ink quantity will adhere for the photoconductor.

Among all the process inks, for controlling the state of photoconductor, the most suitable one is the yellow colour which has the greatest electric conductivity. This enables better adherence of the yellow toner to photoconductor.

The quality of the electrophotographic printing is not in obtaining the prints nearest to the offset standard quality but in obtaining the alignment in produced prints during longer printing period. For less demanding graphic products the illumination of the photoconductor surface up to 131000 times is allowed (the exchange of photoconductor will be caused by mechanical wearing caused by the contact between the photoconductor and the cleaning unit and the portable media).

In the starting 13146 illuminations there are no changes in inking the basic chromatic inks (CMY), which means that the photoconductor does not change its characteristics in its work and that the formed potential is uniformed (-500V). Just tis corresponds with the recommendations of the producers who suggest the exchange of the photoconductor after each 12500 illumination which gives the highest quality of the digital electrophotographic printing.

During the illumination of photoconductor, the colour density in darker tones (50% and 90% screen value) is decreased up to 72495 prints. After 72495 illuminations the laser head cannot compensate this difference in inking during the calibration, because the laser is already set to its maximal strength. In this moment it is recommended the exchange of the photoconductor or the regulation of the voltage by the developing system which can compensate the weaker toner adherence.

6. Literature

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