Colour Shifts in Four Colour Printing

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Abstract

When printing with four colours or more colour shifts depending on natural variations in the level of inking in the printing press can occur. This variation will have negative influence on the grey balance as well as on the colour balance since the variations of the process inks occur randomly and individually i.e. some of the inks can vary in one direction and some in another. This will lead to the fact that density and dot gain can increase or decrease differently for different colours and cause a colour shift.

The aim of the project was:

- To find tolerance limits for colour deviation and a correlation between density deviation and visual acceptance.
- To study how density deviations of the process inks will influence separate colours of the two- and three colour combinations.
- To find a relevant connection between visual appearance and measured data.

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In this study the colours are both colorimetrically measured and visually judged in order to evaluate the influence of the variation of the inking.

A test form was printed first at the optimum level and then with changed density levels, downwards and upwards, for cyan, magenta and yellow, each ink density changed one at a time. Test targets and photographic images were analysed at the different levels.

The results of these tests were:

- Density changes in yellow rendered the greatest and in cyan the smallest visual differences.
- The tolerance limits for density changes became differed for different process inks.
- The colorimetrically measured data and the visual evaluation showed a high degree of correlation.

Background

Problems with colour shifts may arise, when printing with four colours or more depending on the natural variations of the inking level. These variations will have negative influence on both the grey balance and the colour balance, since the variations in the process inks occur both randomly and individually, i.e. some of the inks vary in one direction and some in another. This means that density and dot gain increase or decrease differently for different colours, and this can cause a colour shift. In an earlier investigation (Klaman, Anderson, 1992) it was analysed to what degree, the inking level could deviate without causing an unacceptable grey balance. That study gave a tolerance limit of the solid tones of ± 2,5 %.

The goal of the analysis was:

- To find the tolerance limits of colour based on the correlation between density deviation and visually judged acceptance
- To study the influence of the density deviation of the process colours in two- and three colour combinations
- To find a relevant relationship of visual evaluation and measured data.

In investigations made by NPIRI Task Force on Color Measurement (Bassemir, 1995a and b) colour patches were analysed according to correlation between visual evaluation and measured colorimetric data. Results from these investigations show good correlation between the parameters where the colorimetric data were mostly related to hue changes.

Experimental

A test printing was carried out with print tests made at different levels according to the following conditions. The printing started at the optimum level of print density and dot gain. The density values were then changed for cyan, magenta and yellow, one at the time, in steps of 0,1-density-units.

The test charts were parts of the IT8-testform namely S7A-S10A and the natural images N7A (musicians), N3A (fruit basket) and N1A (portrait) as described in (ISO12640, 1997).
The printing was carried out in a sheet-fed press, Roland Favourite. The paper used was a glossy coated paper 130g.
The density was varied according to table 1.

Colour	**ΔD**			
Cyan	-0,2	-0,1	+0,1	+0,2
Magenta	-0,2	-0,1	+0,1	+0,2
Yellow	-0,2	-0,1	+0,1	+0,2

Table 1. Density changes, nominal values.

Methods

The density was measured with a Gretag D186 with polarisation filter. The density was measured for cyan, magenta and yellow.

The optimum value for each colour exists not only in proof 0 but also in all other proofs where some colour has been changed. Cyan, for example, has the optimum value in nine proofs where the density has been changed for magenta or yellow. For these nine proofs the small unintended density mean deviation ΔD (due to the difficulty to keep the press inking level exactly at the same level during the test-run) has been calculated.

The spectral values were measured with two spectrophotometers, Gretag SPM 100 and X-Rite 938. The technical specifications are seen in table 2. The measured values are calculated for D65 and standard observer 2°.

Function	**Gretag SPM 100**	**X-Rite 938**
Geometry	45°/0°	0°/45°
Measuring area, diameter, mm	3,5	8
Light source	gas-filled wolfram, Illuminant A	gas-filled wolfram approx. 2856°K corr. forD_{65} lightn.
Spectral measuring area, nm	380-730	400-700
Interval, nm	10	20 (calc. 10)
Band width, nm	10	15
Repeatability	0,01 ΔE	0,05 ΔE
Measured parameter	CIELAB	CMC (weighting lightness/chroma 1:2)

Table 2. The technical specifications for two spectrophotometers.

The colorimetric data were calculated according to CIELAB. The colour difference was expressed as ΔE^*_{ab} and as ΔE_{CMC}.. These parameters were chosen since the former is mostly used in the graphic arts literature as a standard (ISO 12647-1, 1996). ΔE_{CMC} is mostly used in the textile and plastic industries but can be of interest for the graphic arts industry as described by e.g. (Pike, 1993), (Clark et al., 1988) and (McLaren, 1986). Attempts to find a better metric for comparing differences in CIELAB has been made by (Dolezalek, 1994). In our case, we used the ΔE^*_{ab} and partly also ΔE_{CMC} to express the colour rendering and we considered it accurate enough in our project as a comparison value to the visual evaluation carried out in the test.

Colorimetric values for cyan, magenta and yellow and red, green and blue were measured in the test form S7A. Ten two- and three colour overprints were chosen and measured. The ten patches were distributed within dark, middle- and light tones.

Visual judgements were carried out to analyse the influence of the density changes on visually experienced colour. A panel consisting of 10 persons evaluated images and colour patches. The proof without density changes was the reference and the other proofs were compared with the reference as being alike or different. Alike in this case means no visual difference. The difference was also described as more bluish, darker or similar. The images that were classified as different also were estimated with respect to be acceptable or unacceptable.

Results

Density values

Table 3 shows the nominal values for the density change, the measured values and the density for the solid tone (mean value of nine measurements).

Ink	**Density change**		**Solid tone density,**
	ΔD Nominal value	**ΔD Measured**	**Df**
C	±0,0	xxx	1,95
	-0,2	-0,22	1,73
	-0,1	-0,11	1,84
	+0,1	+0,10	2,05
	+0,2	+0,24	2,19
M	±0,0	xxx	1,90
	-0,2	-0,15	1,75
	-0,1	-0,12	1,78
	+0,1	+0,09	1,99
	+0,2	+0,20	2,09
Y	±0,0	xxx	1,59
	-0,2	-0,19	1,40
	-0,1	-0,16	1,43
	+0,1	+0,06	1,65
	+0,2	+0,17	1,76

Table 3. Density values.

Colorimetric values for proofs with small density deviations within the optimum level

The proofs at the normal density level i.e. the level without changed densities were in fact never exactly the same when measured i.e. $\Delta E^*_{ab} \neq 0$. An initial test was made where test persons in the panel compared every one of the nine proofs with each other and evaluated if the proofs were different. In table 4 is presented this result.

When calculating ΔE_{cmc} consideration has been taken to the fact that the eye in general is more tolerant to changes in lightness than in chroma and these parameters have been weighted in the formula with 1:2.

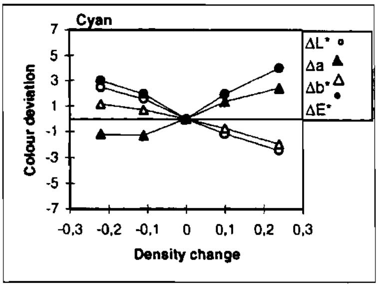
Colour	ΔD	ΔE^*_{at}	ΔE_{cmc}	Perceived different %
Cyan	-0,05<ΔD<0,03	0,50	0,21	44
Magenta	-0,04<ΔD<0,03	0,69	0,34	40
Yellow	-0,02<ΔD<0,04	0,95	0,26	44
Blue		0,71	0,27	38
Green		0,94	0,42	38
Red		0,62	0,24	35

Table 4. Visual judgements and ΔE-values for proofs at the zero-level.

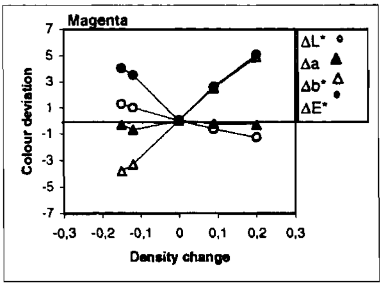
The conclusion drawn from this test is that even small density deviations (unintended changes) causes colour differences with an approximate value of $\Delta E^*_{at} \approx 0{,}7$. About 40 % of the panel have estimated the proofs as different.

Colorimetric values for proofs with density changes

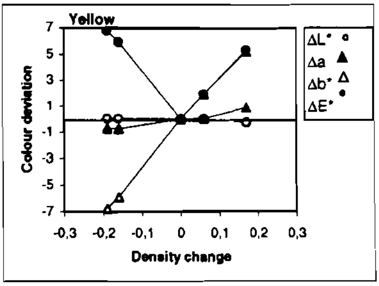
The colour differences between proofs at the optimum level and the proofs with density changes were calculated as follows.
For the proofs at the optimum level the values of L^*, a^*, b^*, C^*_{ab} and h_{ab} were calculated. In the same way the values for the proofs with density changes were calculated and the differences ΔL^*, Δa^*, Δb^*, ΔC^*_{ab} and ΔH^*_{ab} as well as the values of the total differences ΔE^*_{at} and ΔE_{CMC} were measured for the solid tones of cyan, magenta and yellow and the corresponding two colour combinations blue, green and red. In order to study the effect of the density changes on the colour components the relationship has been visualised in figure 1 and 2.
The ink order at printing was KCMY. The point for the nominal optimum level (0.00) has been pointed out.



1A

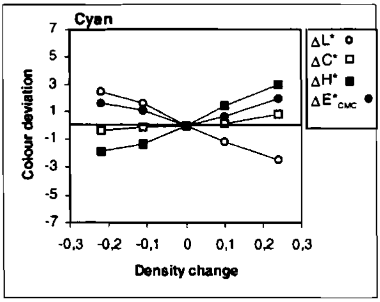


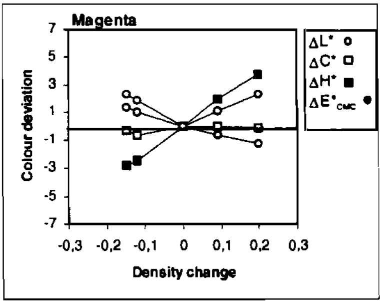
1B



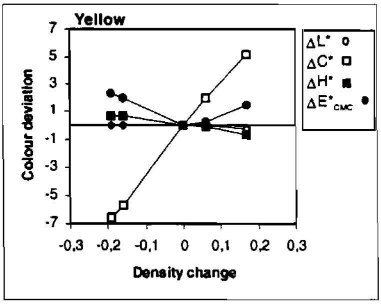
1C

Figure 1A-C *Colour deviation expressed as ΔL^*, Δa^*, Δb^* och ΔE^*_{ab} of proof with density changes in cyan, magenta and yellow.*





2A *2B*



2C

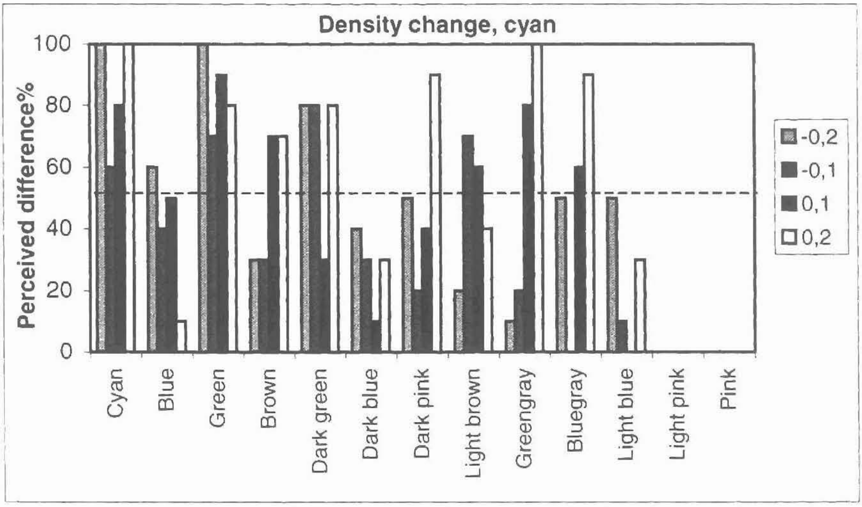
Figure 2A-C *Colour deviation expressed as ΔL^*, ΔC, ΔH_a^* och ΔE^*_{CMC} of proofs with density changes in cyan, magenta and yellow*

The following conclusions can be drawn from the figures:

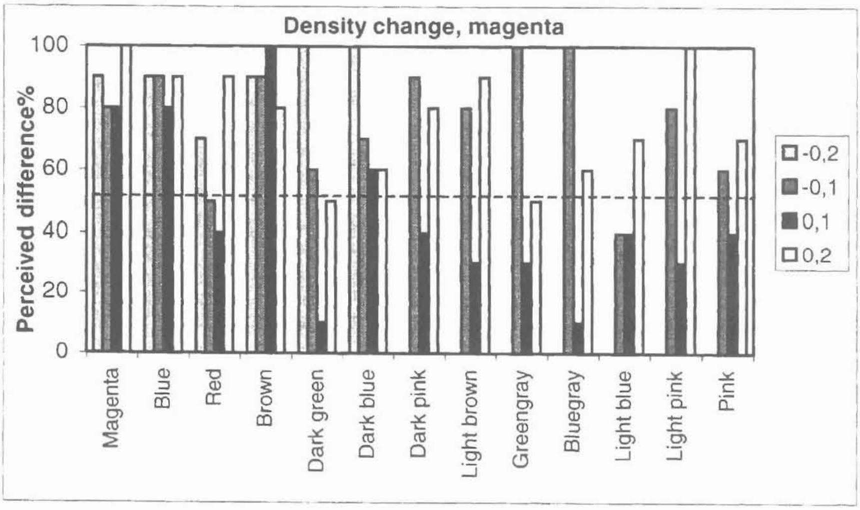
- Density changes give different magnitudes to the colour difference value of ΔE^*_{ab}. A density change of ± 0,2, for instance, give the values $\Delta E^*_{ab} \approx 3$ for cyan, $\Delta E^*_{ab} \approx 5$ for magenta and $\Delta E^*_{ab} \approx 7$ for yellow.
- The most obvious change in colour is in the chromaticity components with a change of the values of ΔC^*_{ab} and ΔH^*_{ab}.

Result visual judgements

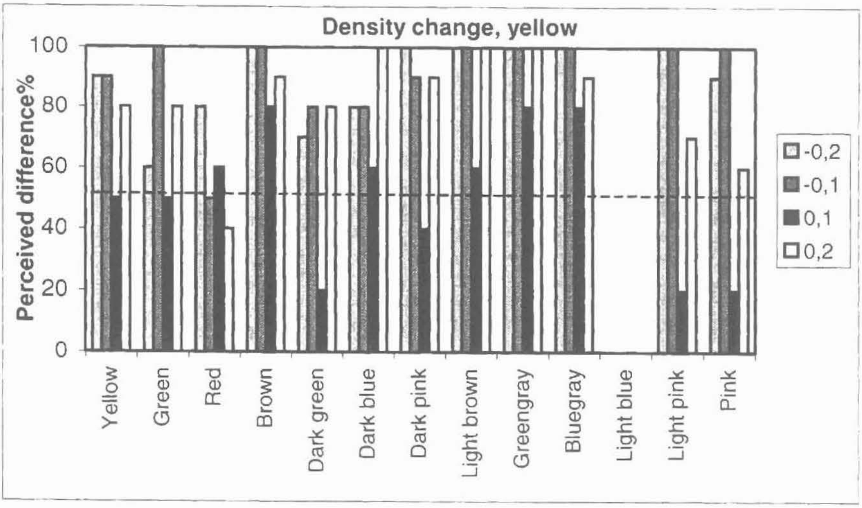
The result of the judgement of the 16 colour patches is shown in figure 3. Here it is shown how the four density levels influence the different colour patches and what influence changes of the different process inks will have. According to the initial tests where 40 % of the test panel estimated the small unintended density deviations to cause a difference an acceptance limit was decided to 50 %, i.e. a limit with a clear marginal to the 40 %. This 50 % limit is the level where 50 % of the panel perceived the proof as different from the reference.



3A



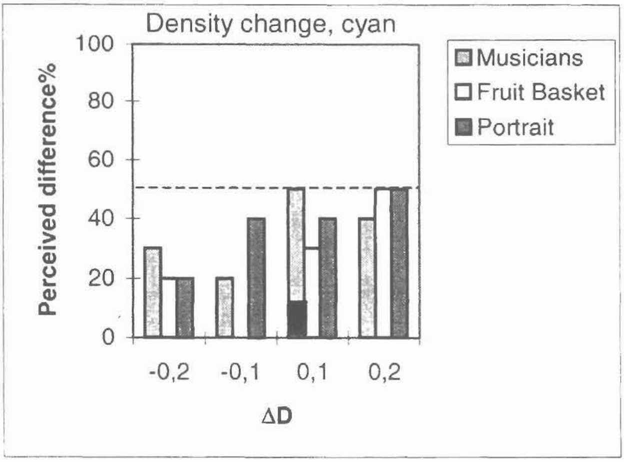
3B



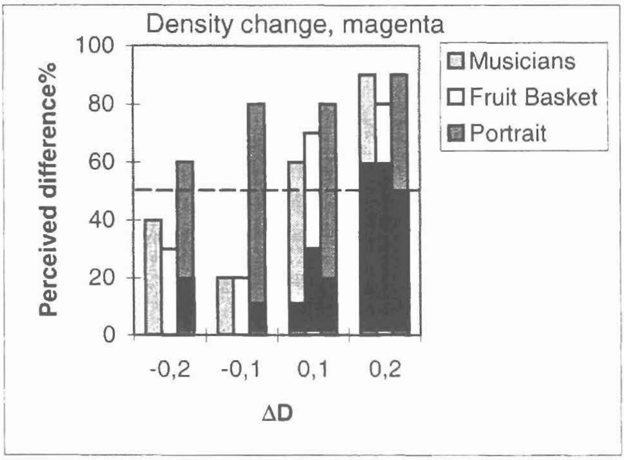
3C

Figure 3A-C. *Visual judgement of the 16 colour patches at different density levels.*

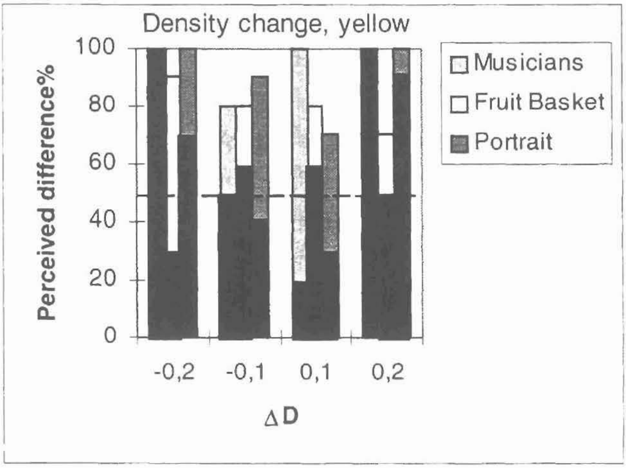
Figure 4 shows in a similar way the result of the evaluation of the influence of density changes of the three images described earlier. The x-axes show the density change and the y-axis the percentage of the panel that has estimated the image as different and as unacceptable. By difference, is meant the perceived colour difference. For the images Musicians and Fruit Basket, the entire image was judged and for the image Portrait, the skin tones were judged. The 50 %-level is marked in the figure.



4A



4B



4C

Figure 4A-C Visual judgements of the three images at the different density levels. The black staples indicate the percentage of the panel who has judged the image quality as unacceptable in comparison with the reference that is the image at the density level without change.

The density changes of cyan, especially for decreased values, are more acceptable than those for magenta and yellow. Density changes of yellow are the ones least acceptable i.e. the test panel did not fully accept any of the images. For magenta, the tolerance limit is due to the image character. Images with skin tones have a more limited tolerance interval than other images. The result from the remarks given by the test panel due to the differences noted as for instance, more bluish, also gave the same kind of information in the measured values, in this case a negative b*-value i.e. more bluish.

In figure 5 the ΔE^*_{ab}-values are plotted against the ΔD-values where the ΔD is the change from the optimum level for each one of the process inks. From the figure can be concluded that the same change in density give different values for the ΔE^*_{ab}.

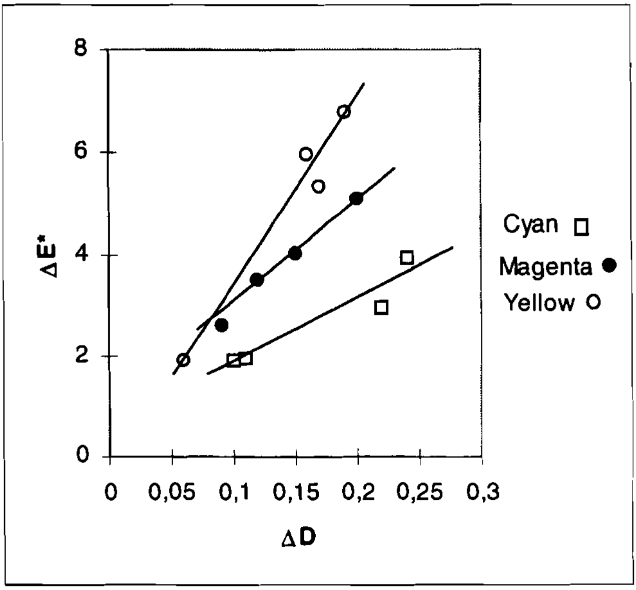


Figure 5 *Density changes of the process inks cause different magnitude of ΔE^*_{ab}*

Conclusion of the visual judgements and colorimetric measurements

- Density changes of yellow gives the largest visually perceived difference and cyan the smallest.
- A decrease of the density value with 0,1 in magenta gives in the middle tones a visually perceived difference of approximately 90 % of the panel. The same decrease of yellow causes a difference of approximately 100 % and of cyan with 30 %.
- A comparison of the values of ΔE^*_{at} it shows the same result with the highest value for yellow and the lowest value for cyan.
- There is a relationship between the visually perceived appearance of an image and the measured colour components. A negative value, for instance of Δb^* by e.g. with a larger part of blue component, also gives a visual appearance more bluish than the reference.
- The level of unacceptance stresses clearly the larger influence of changes in yellow than in cyan (and magenta).

It can be concluded from this test that the tolerance intervals of the density deviation can be set to the numbers showed in table 5. The acceptance level is somewhat higher that the judged difference level, which implicates that a small difference in image quality can be accepted.

Image	**Cyan, ΔD**	**Magenta, ΔD**	**Yellow, ΔD**
	Visually perceived difference		
Musicians	±0,2	$-0{,}2<\Delta D<0{,}1$	<0,1
Fruit Basket	±0,2	$-0{,}2<\Delta D<0{,}1$	<0,1
Portrait	±0,2	$-0{,}1<\Delta D<0{,}1$	<0,1
	Unacceptable image quality		
Musicians	±0,2	$-0{,}2<\Delta D<0{,}15$	±0,1
Fruit Basket	±0,2	$-0{,}2<\Delta D<0{,}15$	±0,1
Portrait	±0,2	$-0{,}2<\Delta D<0{,}15$	±0,1

Table 5 *Tolerance interval of density deviations*

A tolerance limit of the solid tone density of ± 0,1 can be considered enough for an acceptable quality. It is however preferable to keep the deviations of yellow lower than the limit of ± 0,05 since a deviation of yellow of ± 0,05 up to 0,1 is comparable with a deviation of cyan of ± 0,2.

Conclusions

- The magnitude of the colour difference expressed as ΔE^*_{at} with the values $\Delta E^*_{at} \approx 3$ for cyan, $\Delta E^*_{at} \approx 5$ for magenta and $\Delta E^*_{at} \approx 7$ for yellow at a density change of ± 0,2.
- The chromaticity components exhibit the most obvious change of colour when the values of ΔC^*_{ab} and ΔH^*_{ab} change.
- Density changes of yellow gives the largest visually perceived difference and of cyan the smallest.
- When comparing the values of ΔE^*_{at} the same results are seen i.e. the highest value for yellow and the lowest value for cyan.
- The measured data and the visually judged data show a god correlation.
- A tolerance limit of the solid tone density of ± 0,1 can be considered enough for an acceptable quality. It is however preferable to keep the deviations of yellow lower than the limit of ± 0,05 since a deviation of yellow of ± 0,05 up to 0,1 is comparable with a deviation of cyan of ± 0,2.

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Literature cited

Bassemir, R., *A*

1995 *Comparison of Visual and Spektrophotometric Evaluation of Paired Color Prints,* TAGA Proceedings.

Bassemir, R.,

1995 *Visual and Spectrophotometric Evaluations of Paired glossy prints having selected ΔE* values,* TAGA Proceedings.

Clark, F. J. J., MacDonald, R., Rigg, B.,

1988 *Modification to the CMC colour-difference formula,* Text. Chem. Color, 1988. 20(6), p 128-132.

ISO/DIS 12640,

Graphic technology -Prepress digital data exchange- Standard colour image data (SCID).

Klaman, M., Anderson, I.,

1992 *Densitetsförändringars inverkan på gråbalansen,* GFL Projektrapport nr 75, Juli 1992.

McLaren, K.,

1986 *The colour science of dyes and pigments,* 2nd ed. 1986, Bristol: Adam Hilger. 209 p.

Pike, I. T.,

1993 *The Fit of Various Color Tolerance Methods to Normal Printing Color Variations,* IS&T's Third Technical Symposium on Prepress, Proofing & Printing.

Dolezalek, F. K

1994 *Appraisal of Production Run Fluctuations From Color Measurements in the Image,* TAGA Proceedings, Pg. 154 – 164

ISO-standard 12647-1,

1996 *Graphic Technology – Process control for the manufacture of half-tone colour separations, proof and production prints – Part 1: Parameters and measurement methods.*

Selected bibliography

Bristow, J. A., Klaman, M., Hoc, M.,

1993 — *The comparison of colour gamuts*, IARIGAI's 22nd International research conference in Munich, September 1993 and PFT-report nr 1.

Robertson, A. R.,

1977 — *The CIE 1976 color difference formulae*, Color Res. Appl., 1977. 2(1), sid 7-11.

Rydefalk, S., Wedin, M.,

1997 — *Literature Review on the Colour Gamut in the Printing Process, Fundamentals*, PFT-report nr 32.

Stanziola, R.,

1994 — *Colorimetry and the Calculation of Color Difference*, Part II, American Ink Maker, Januari 1994, p. 25-40, 66-67, 73.