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STUDY ON THE QUALITY OF REPRODUCTION OF GRAPHICAL LINEAR MICRO-IMAGES USING ELECTROPHOTOGRAPHIC PRINTING

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Abstract

Today's market of visual graphic communication includes many various advertising, publishing and packaging products printed on different materials. Many products are printed using conventional printing technologies such as offset printing or flexography, in addition to digital ones like Electrophotography and Ink Jet.

The graphic images on prints often contain extremely fine graphic details, such as micro-lines or micro-text elements, which are part of various identification, security markings, codes, etc. It is a very important task to optimally model these micro-images on printed graphic communication products at the design stage, in order to ensure their brightness, legibility and geometric dimensions meet the requirements, not only immediately after printing, but also, for example, after a certain period during the life cycle of the printed product after exposure to the sunlight spectrum, or to other mechanical or environmental effects.

This paper presents a methodology and results for the assessment of the quality of the reproduction of fine image details, i.e. the micro-lines of different widths arranged on the print in different directions. A specially developed original digital press quality control wedge with monochromatic micro-lines, microtext and screen dots bars of CMYK colours was applied to assess the accuracy of micro-image reproduction. In this part of the study, the wedge fields with positive micro-lines arranged in different directions individually and in groups were analysed. The width of the micro-lines was measured under the microscope to assess the accuracy of the dimensional reproduction and the deviations from the nominal value. To assess the influence of different parameters of the system "printing press-paper-inks" on the reproduction of image microelements, the prints for this part of the study were printed using electrophotographic printing techniques on different dry-toner printing presses on different types of paper.

The width and deviations of the micro-lines on the print were measured along the print direction, perpendicular and at 45° to the print direction.

Measurements of the reproduction accuracy of monochrome micro-line

images, printed on dry-toner electrophotographic presses, showed that the accuracy of micro-line reproduction depends not only on the printing system, its resolution and the characteristics of the paper, but also on the direction of the positioning of the micro-lines on the printed sheet.
The obtained results allow us to compare the capability of digital printing systems to reproduce linear micro-images on visual graphic communication products of any size and geometric orientation, to select optimal systems for printing specific products, and to model the layout of micro-images on products at the design stage, by assessing the orientation of the micro-images on the printed sheet.
Keywords: *Electrophotography, digital printing, control wedge, micro-lines, print quality.*

Introduction

In addition to offset and flexographic printing, Electrophotography and Inkjet digital printing technologies are often used for different reasons to print modern graphic communication products. As in all printing technologies, in addition to accurate colour rendering on print, there is also equally important quality of printing of thin micro details of the image. The quality of printing of the micro-images, the geometric definition, accuracy and legibility of their elements, including identification by automated techniques, depend on many parameters: the resolution (dpi) of the digital press, the properties of the printing materials, the composition and physical characteristics of the ink, etc.

Modern electrophotographic and Inkjet printing presses can be used to produce high-quality products. Although, for example, the quality parametres of offset printing are often higher (Yılmaz U. et al, 2021; Mai Ch., Hoang T., 2023), those two digital printing technologies can also be successfully used for medium or small runs of packaging, advertising publications or other high-quality products, as well as for prints with micro-images such as thin 0,05–0,2 mm monochrome micro-lines, micro-type, screen dots and other image details forming various code or other purpose micro-image systems on the print. These marks are often scanned by special automated devices, therefore, the accuracy of the reproduction of the micro-image details, their resolution, the homogeneity of the line and spacing widths, and the uniformity are very important. For example, micro QR code symbols, printed with low contrast, non-uniformity of disconnected dots or other defects, may not be readable by a scanner (ISO/IEC 18004:2015).

As different electrophotographic and Inkjet digital printing systems differ in their ability to precisely reproduce image micro-elements on the print, it is important not only to control the reproduction of these elements, but also to accurately model images with micro-lines or micro-type at the design stage, taking into account the ability of the printing systems to reproduce them. Currently, various digital print quality control wedges are used to ensure the reproduction accuracy of graphic micro-images, yet they lack information to allow the accuracy of reproduction of a wide range of micro-lines and various monochromatic micro-images to be monitored conveniently even under production conditions.

Predictable print quality issues have been discussed by various authors. For example, the Fogra Research Institute for Media Technologies (Kraushaar A., 2022) provides requirements and recommendations for data preparation and digital colour printing. When defining the requirements for a digital print, the following aspects are highlighted such as colour reproduction, detail sharpness and homogeneity of the printed production (A. Kraushaar, 2022, p. 70). Barcodes (1D) and matrix codes (2D) on a variety of papers and packaging materials are also often printed, for example, on Inkjet printing systems. The Fogra Barcode Test bar was developed for visual and metrological evaluation of barcodes (Fogra Research Project Barcode (11.004), 2021). Optimisation of the quality assessment process of barcodes printed using inks with magnetic properties, assessment of barcode line width, uniformity and edge irregularity, the accuracy of the reproduction of lines and intervals is important for accurate automated reading of barcode information (Havenko S. et al, 2020).

For the control of micro-images with details significantly finer than the lines in the barcodes in Inkjet systems, for example, a specific test-object has been proposed with micro-lines of different orientations and widths (Sysuev I. et al, 2019). This test-object also focuses on the orientation of the micro-lines to assess their reproduction on the print when using Inkjet printing presses.

The specifics of electrographic printing are fundamentally different from Inkjet. In terms of laser imaging technologies, the original control wedge was developed to assess the quality of reproduction of images on offset digital thermosensitive printing forms on Computer-to-Plate (CtP) systems with high 2400–3200 dpi resolution and above, including the possibility to assess function of modulation transfer (Sajek D., Valčiukas V., 2011; Sajek D., 2014; Sajek D., Valčiukas V., 2021). This control wedge was also used to control 0,01–0,15 mm micro-lines positioned in different directions, allowing to assess the micro-line reproduction inaccuracies over a wide range of dimensions as the laser image is formed parallel, perpendicular and at a 45˚angle to the direction of laser head movement.

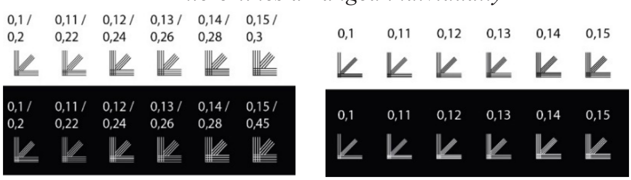
Methodology and equipment

The study aims to develop a universal control wedge, which can be used to control and pre-model the reproduction quality of thin linear micro-images over a wider range, printed by various digital printing techniques on different materials. In this part of the study, a control wedge will be used to control the quality of the reproduction of micro-lines on electrophotographic prints produced with dry inks.

This original control wedge was developed in Adobe Illustrator. It consists of monochromic micro-lines, micro-font and screen dots fields in CMYK colours, and other control elements. This part of the study deals with the control wedge part, which is used to control the accuracy of the reproduction of micro-lines.

The whole control wedge micro-line part consists of micro-lines ranging from 0,01 mm to 0,15 mm in width, varying in 0,01 mm intervals in the positive and negative fields aligned individually (Fig. 1) and in groups, respectively. Fragments of the control wedge (Fig. 2) show the micro-lines are aligned individually with double-width spacing (Fig. 2, a) and in groups with equal-width spacing (Fig. 2, b). The micro-lines are aligned parallel, perpendicular and at an angle of 45˚ to the print direction in the positive and negative fields of the wedge.

Fig. 1. The part of the control wedge for 0,01–0,15 mm width positive and negative micro-lines arranged individually



a *b*

Fig. 2. Fragments of the control wedge of 0,1–0,15 mm width positive and negative micro-lines a) arranged individually; b) in groups

The accuracy of the reproduction of micro-lines for the following systems "printing press-paper-ink" was assessed. The print tests were printed on electrophotographic presses *Xerox Versant 280 Press (Press 1)* and *Ricoh Pro C5200S* (*Press 2*) using dry ink (toner) at 1200 dpi and 2400 dpi resolution. The papers selected for the print run were Novatech Digital Silk (200 g/m^2) and Image Digicolor (70 g/m^2), which are often used in digital printing. Both types of paper have a relatively high surface smoothness: the measured R_a Novatech Digital Silk is 0,504 µm along to the direction, 0,589 µmin perpendicular the direction; Image Digicolor R_a is 0,497 µm along to the direction, 0,576 µm perpendicular the direction. Standard ink (black toner) for printing on *Xerox Versant* and *Ricoh Pro* printers was used.

The width of the micro-lines on the prints was measured using a digital microscope Dino Lite AM4013MT (Fig. 3).

Fig. 3. Digital microscope Dino Lite AM4013MT (magnification 10–70×, 200×)

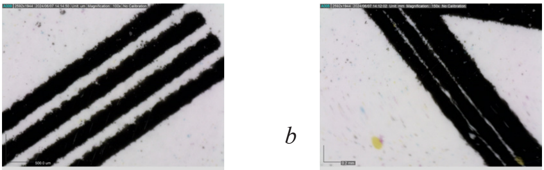
5 prints were printed with the identical parametres on both types of paper. 1200 dpi resolution, 150 lpi and 200 lpi was used in *Press 1, whereas* 1200 and 2400 dpi resolution, and 200 lpi using Press 2. After selecting two prints without visual defects, the widths of the micro-lines were measured immediately after printing and deviations were determined. The remaining prints will be used in the next stage of the study to determine the level of environmental (lighting, humidity), temporal (ageing), mechanical (rubbing) effects and the variation in the colour properties of the prints and the dimensions of the micro-lines.

Micro-lines from 0,01 mm to 0,15 mm, aligned with the print direction (parallel) and perpendicular and at a 45˚ angle to the print direction, were assessed. The lines were measured with a *Dino Lite AM4013MT* microscope. The lines aligned individually with double-width spacing, and those aligned in groups with equal-width spacing, were measured by taking the lines from the middle of the group (Lines 2 and 3). The width of the lines was measured 5 times each, and the average was derived. Unstable, uneven and blurred lines without spacing, the width of which could not be assessed, were rejected as not being precisely reproduced on the print.

Results

The results of the micro-lines width measurements on the prints produced with *Press 1* showed that virtually stable reproduction of the micro-lines is possible only from 0,06 mm when the lines are aligned in groups with equal-width spacing and oriented to the print direction. When using 150 lpi, reproduction of micro-lines, is better, than using 200 lpi; it is evident especially on Novatech Digital, 200 g/m^2.

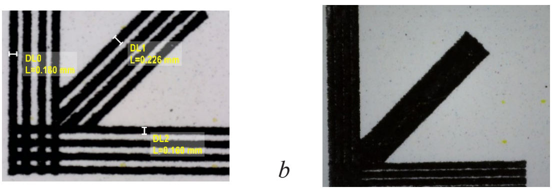
When micro-lines are aligned individually, using 1200 dpi resolution and 200 lpi, reproduction of 0,04 mm micro-lines is reasonably good. The reproduction of the 0,08 mm micro-lines and above can be considered stable, but the accuracy of the reproduction depends on the position and the resolution; the gain in the width is significant, amounting to between 20 % to 50 % on average. As the width of the micro-line increases, the relative gain in its width decreases (Table 1, Fig. 4).



a *b*

Fig.4.Microphotographs of 0,08 mm micro-lines: a) separate line; b) line in group. Press 1 print, 1200 dpi, 150 lpi, Image Digicolor 70 g/m^2

The results of the micro-lines measurement on the prints produced with *Press 2* show that stable micro-line reproduction in this system starts at 0,08–0,1 mm when the micro-lines are aligned individually with double-width spacing, but when the micro-lines are aligned individually with double-width spacing, 0,08–0,1 mm width micro-lines are only reproduced at 1200 dpi resolution (200 lpi); when printing at 2400 dpi resolution (200 lpi), only a stable reproduction of 0,12–0,15 mm width of these micro-lines can be expected, but with a significant width gain of approximately 80% (*Table 2, Fig. 5*).



a *b*

Fig.5. Microphotographs of 0,1 mm micro-lines: a) separate line; b) line in group; Press 2 print, 1200 dpi, 200 lpi, Novatech Digital 200 g/m^2

Table 1. Results of micro-lines width measurement. Press 1

No.	Paper, g/m²,	dpi/ lpi	Approx. width of micro-line, mm (in file)								Position to print direction	Gap width, ×
			0,01	0,04	0,05	0,06	0,08	0,1	0,12	0,15	Per ‖ Par ═	×1, 2
			Approx. width of micro-line, mm (print)									
1	Novatech Digital, 200	1200/200	–	–	–	n	0,12	0,12	0,15	0,17	Per ‖	×1
			–	–	–	0,10	0,12	0,13	0,15	0,18	Par ═	×1
2	Novatech Digital, 200	1200/200	–	0,06	0,08	0,10	0,13	0,14	0,16	0,20	Per ‖	×2
			–	0,06	0,09	0,10	0,12	0,13	0,15	0,18	Par ═	×2
3	Novatech Digital, 200	1200/150	–	–	n	n	0,12	0,13	0,16	0,19	Per ‖	×1
			–	0,06	0,08	0,10	0,13	0,14	0,16	0,20	Par ═	×1
4	Novatech Digital, 200	1200/150	–	–	0.07	0.08	0,12	0,13	0,16	0,19	Per ‖	×2
			–	–	0.08	0.08	0.14	0.12	0,16	0.20	Par ═	×2
5	Image Digicolor 70	1200/200	–	–	–	–	0.13	0,12	0,15	0,19	Per ‖	×1
			–	–	0.08	0.08	0.14	0.12	0,16	0.20	Par ═	×1
6	Image Digicolor 70	1200/200	-	-	-	-	0.13	0,13	0,15	0,19	Per ‖	×2
			-	-	0.08	0.08	0.14	0.12	0,16	0.20	Par ═	×2
7	Image Digicolor 70	1200/150	-	-	-	-	0.12	0,12	0,14	0,19	Per ‖	×1
			-	-	-	-	n	0.13	0.16	0.20	Par ═	×1
8	Image Digicolor 70	1200/150	-	-	-	0.10	0.12	0.13	0.16	0.20	Per ‖	×2
			-	-	n	0,11	0.14	0.14	0.17	0.21	Par ═	×2

n – impossible to measure

Table 2. Results of micro-lines width measurement. Press 2

No.	Paper, g/m^2,	dpi/lpi	Approx. width of micro–line, mm (file)								Position to print direction	Gap width, ×
			0,01	0,04	0,05	0,06	0,08	0,1	0,12	0,15	Per ‖ Par =	×1, 2
			Approx. width of micro–line, mm (print)									
1	Novatech Digital, 200	1200/200	–	–	–	–	0.11	0.14	0.15	0.20	Per ‖	×1
			–	–	–	–	0.11	0.15	0.16	0.20	Par =	×1
2	Novatech Digital, 200	1200/200	–	–	0.10	0,10	0.12	0.14	0.17	0.20	Per ‖	×2
			–	n	0.11	0.10	0.14	0.15	0.18	0.21	Par =	×2
3	Novatech Digital, 200	2400/200	–	–	–	–	n	n	0.22	0.24	Per ‖	×1
			–	–	–	–	n	n	0.23	0.24	Par =	×1
4	Novatech Digital, 200	2400/200	–	–	–	n	0.13	0.16	0.18	0.22	Per ‖	×2
			–	–	–	n	0.14	0.20	0.21	0.25	Par =	×2

n – impossible to measure

For *Press 1*, the micro-lines aligned individually parallel to the print direction was found to have a greater width gain than the lines aligned perpendicular to the print direction (Fig. 6, 7). The change in line widths depends on the paper, in particular for micro-lines of 0,04–0,08 mm width, as they are more unstable when they are printed on a thinner paper such as Image Digicolor 70 (Fig. 7).

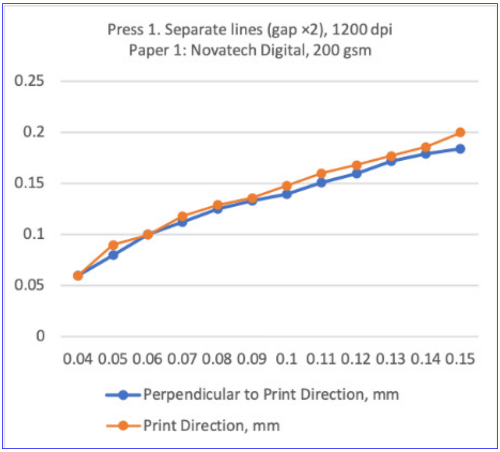


Fig. 6. Micro-lines printed on Press 1, Novatech Digital (200 gsm)

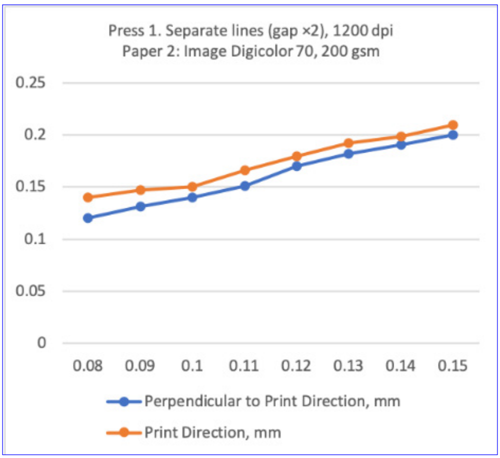


Fig. 7. Micro-lines printed on Press 1, Image Digicolor (70 gsm)

For *Press 2* it was found out, that when using 1200 dpi, thin micro-lines (0,06–0,1 mm) are reproduced better than when using 2400 dpi; stable reproduction can be achieved from 0,08 mm for lines in groups, and from 0,06 mm – for separate lines.

When using 2400 dpi, the reproduction of thin micro-lines (0,08–0,1 mm) is worse, especially for lines in groups – even in a group of 01 mm width lines, the small gaps begin to appear when the micro-lines are oriented perpendicular to print direction; when parallel– the lines merge. The micro-lines width gain for 2400 dpi is more significant than using 1200 dpi, for example, separate 0,1 mm micro-lines oriented to the print direction reproduced as 0,2 mm; separate 0,15 mm micro-lines, orientated to the print direction, reproduced as 0,25 mm – the gain is up to 100 %, whereas when using 1200 dpi resolution, accordingly; separate 0,1 mm width micro-lines oriented to the print direction, reproduced as 0,15 mm (50 % gain); separate 0,15 mm width micro-lines oriented to the print direction, reproduced as 0,21 mm. The width gain of all the micro-lines (in groups and separately) is more significant when printed on 2400 dpi, especially when the lines are directed to the print (Table 2, Fig. 8, 9).

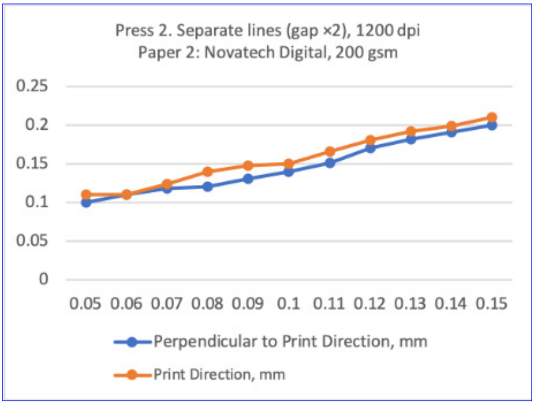


Fig. 8. Micro-lines printed on Press 2, 1200 dpi

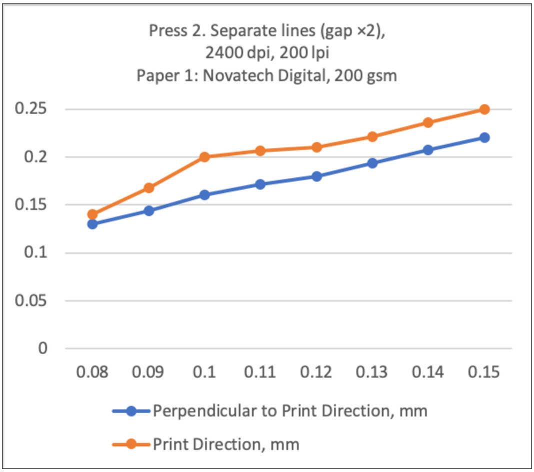


Fig. 9. Micro-lines printed on 2400 dpi

Conclusions

The study showed that the original control wedge with a large range of micro-lines with different widths and arrangements can be successfully used to assess the quality of digital prints with linear micro-images.

Comparison of prints produced with two electrophotographic printing systems working with dry inks (toner), and measurements of the reproduction accuracy of monochrome micro-line images showed, that the accuracy of micro-line reproduction depends not only on the printing system, its resolution and the characteristics of the paper, but also on the direction of the positioning of the micro-lines on the printing sheet. The composition and properties of the inks, as well as the type of paper and the surface morphology, can also influence the accuracy of the reproduction of micro-images, therefore these factors will be assessed in further study.

The results allow a comparison of the capabilities of electrophotographic digital printing systems to reproduce linear micro-images on visual graphic communication products of any size and geometric orientation, to select optimal systems for printing and to model the layout of micro-images at the design stage, by assessing the orientation of the micro-images on the printed sheet.

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