Large Drop Volumes From Xaar-Type Inkjet Printheads

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Abstract

While the trend for high resolution, photo quality printing demands inkjet drop volumes of a few picoliters, there are other applications that require large drop volumes for low resolution, high optical density printing. By modification of standard Xaar-type piezo inkjet printheads ink drops of more than 150 pl volume could be produced. Controlled drop formation was obtained, channel starvation did not occur, and the printhead appeared robust against misfiring, so that no channels were lost when printing even odd pattern for extended times.

In a further development step each ink channel was equipped with four nozzles, arranged in a square. In this fashion ‚square dots' were printed, which perfectly filled the square pixels of a 185 dpi raster. Consequently high quality line pattern could be printed on several inkjet papers at optical densities larger than 2 in a single pass.

Introduction

Inkjet printing with high optical density typically requires multi-pass printing modes. Here we present an approach to print high optical density in a single pass with a Xaar-type piezo inkjet printhead at 185 dpi resolution.

To that aim a standard Xaar-type XJ126/200dpi printhead was modified in consecutive steps. In the first step the printhead was modified to increase the inkjet drop volume in order to deliver more ink to the substrate and thus increase the optical density. We here refer to these printheads as '1× large drop' printheads, where '1×' indicates one nozzle per channel. In the second step the printheads were equipped with nozzle plates that contained four nozzles for each individual ink channel with the goal to print four individual ink drops per pixel, and to fill out each pixel area on the substrate with a 'square dot'. These printheads are referred to as '4× large drop' printheads in this presentation.

In the following the two different printheads and their respective drop formation will be described. Print tests with the different printheads further demonstrated that high optical density printing at 185 dpi was possible as presented below.

The '1× Large Drop' Printhead

The vehicle for the present investigation was Xaar's XJ126 printhead with 200 dpi resolution. This is a piezo inkjet printhead based on the shared wall and shear mode principle. The actuator as depicted in Fig. 1 is designed as an end-shooter with ink channels of 75 µm width and 380 µm depth. The channel wall width of 62 µm results in a 137 µm channel pitch and yields a high linear density of 185 dpi. The nozzle plate at the front end of the actuator contains nozzles with a diameter of 50 µm. This XJ126/200 printhead delivers drops of 70 pl at a print frequency of 5.5 kHz. The actuator walls are produced as monolithic cantilevers. By applying appropriate voltage waveforms to the channel electrodes the channel walls perform controlled motions. These induce an acoustic pulse in the ink within the channel, which effects the formation of an ink drop at the nozzle. The 126 ink channels are sequentially fired in 3 phases so as to allow for drop formation at adjacent channels. For further details of Xaar-type printheads refer to the literature.[1–4]

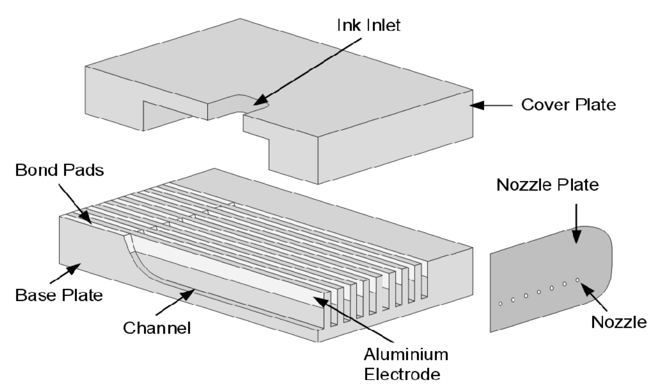


Figure 1. Cross section through a Xaar-type end-shooter printhead

To obtain a '1× large drop' printhead several modifications were applied to the XJ126/200 printhead. The channel width was increased to 102 µm, while the channel depth was kept unchanged. This resulted in channel walls of only 35 μm thickness, as shown in the front view of the actuator in Fig. 2. The second modification was the increase of the nozzle diameter from 50 μm to 56 μm. The third modification related to the electrical voltage waveform, which had to be adapted to the new channel geometry and nozzle diameter for optimum drop formation.

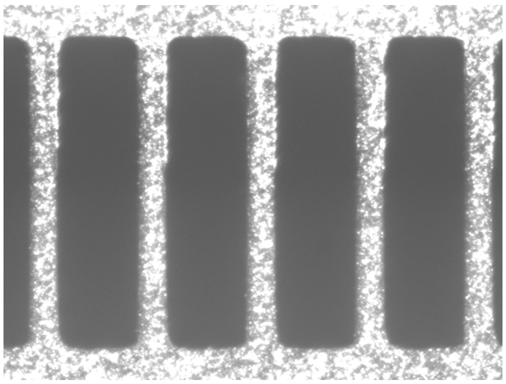


Figure 2. Front view of the 'large drop' actuator with 35 μm channel walls

Changing the channel width from 75 to 102 μm altered the acoustic length of the actuator. An optimum clock frequency of 478 kHz was evaluated for the '1× large drop' printhead. At this clock frequency the drop velocities of the three print phases a, b and c had lowest spread. The resulting maximum printing frequency of 4.9 kHz was thus lower than the 5.5 kHz of the standard XJ126/200 printhead.

The drop volume measurements were carried out with a balance. Oil-based ink was used, the drop velocity was set to 6 m/s, and the printhead temperature was kept at 24 ±1°C during the tests. For the present measurements either 16 channels, representing low duty printing, or 126 channels, representing 100% printing, were fired into a container placed on a balance. Figure 3 shows the ink drop volume as a function of printing frequency for both, the '1× large drop' printhead and for the XJ126/200 printhead as a reference. For the XJ126/200 printhead the drop volume was measured to be a constant 66 pl. It did neither depend on printing speed nor on the number of channels printing. This indicated that there was no starvation of ink flow throughout the range of operation of this printhead. The '1× large drop' printhead delivered ink drop volume in the order of 150 pl. With 16 channels printing the drop volume was essentially constant throughout the range of printing frequencies up to the operational limit of 4.9 kHz. However, printing all 126 channels resulted in a 12% decrease of drop volume at the highest printing frequency. From these observation it was concluded, that channel starvation did not occur, and that the starvation effect at 100% printing was due to flow restriction within the ink delivery system outside the actuator. The ink feed system of the 'large drop' printheads had not yet been modified for these investigations.

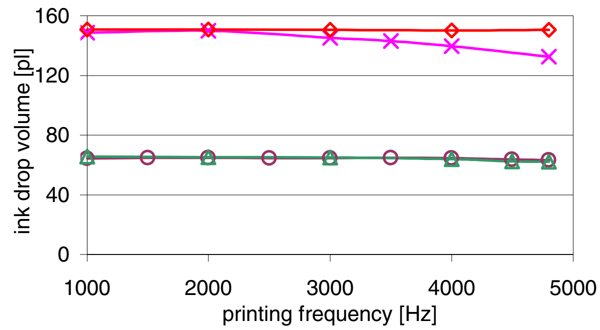


Figure 3. The ink drop volume as a function of printing frequency for the '1× large drop' printhead at (◊) 16 channels printing and (×) 126 channels printing, as well as for the XJ126-200dpi printhead at (o) 16 channels printing and (Δ) 126 channels printing

Further tests revealed that the drop angle deviation was similar to that of the standard XJ126/200 printheads. The same holds for the driving voltage to reach the nominal drop velocity of 6 m/s. No misfiring was observed for extended times so that drop formation appeared to be stable even for odd print pattern at full printing frequency.

The '4× Large Drop' Printhead

Nozzle plates that provided four nozzles per ink channel were assembled onto the wide-channel actuator to produce the '4× large drop' printheads. The nozzle centers were placed onto a 62 μm square grid, and the four individual nozzles had outlet diameters of 28 μm, so that all four nozzles had the same total area as the one nozzle of the '1× large drop' printhead. The front view of the printhead in Fig. 4 shows the placement of the nozzle plate on the channel walls, the size of which is indicated by the dotted lines. The channel size appears to be smaller than in Fig. 2 due to the glue meniscus, which is visible through the transparent nozzle plate.

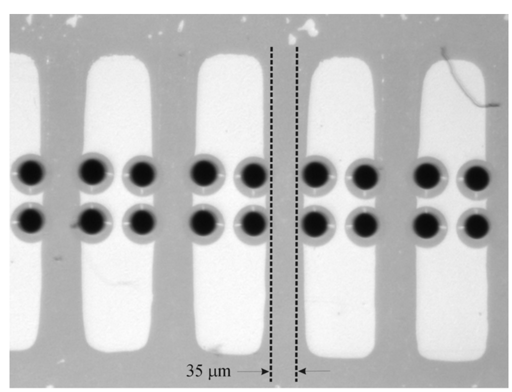


Figure 4. The front view of the '4× large drop' printhead with the nozzle plate assembled. The dotted lines indicate the size of the channel walls.

Drop formation with the '4× large drop' printheads was investigated under a microscope with stroboscopic illumination. It became apparent that higher driving voltages were needed as compared to the '1× large drop' printhead. This was expected due to the higher total flow resistance in the four small nozzles. With optimized driving parameters stable drop formation could be obtained. Fig. 5a shows a photograph of the drop ejection from a '4× large drop' printhead firing all channels in 3 phases. Groups of four drops were ejected from each channel. The printhead was slightly tilted for these photographs to be able to visualize all four drops per channel. The stable drop formation and propagation is demonstrated in this photograph. Figure 5b gives a close view of a single group of four ink drops, which propagate on parallel trajectories separated by 62 μm.

Most important results of these tests were the observations that four individual ink drops were formed, which traveled on parallel trajectories and with very similar drop velocities. These facts enabled to print 'square dots', which will be described in the next chapter.

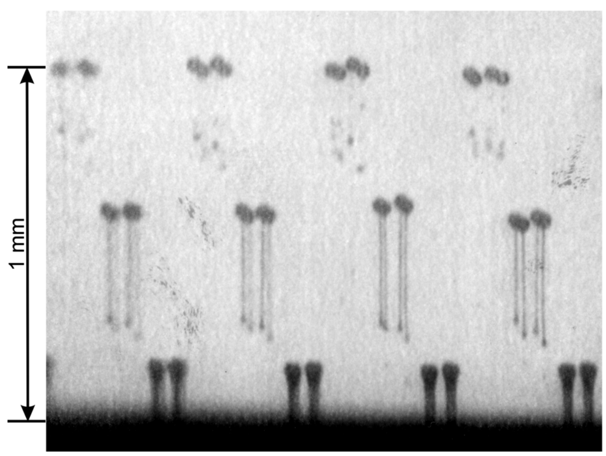


Figure 5a. Drop ejection from a '4× large drop' printhead firing all 3 phases a, b and c. Groups of four drops were ejected from each channel. The printhead was slightly tilted for this photo to visualize all four drops.

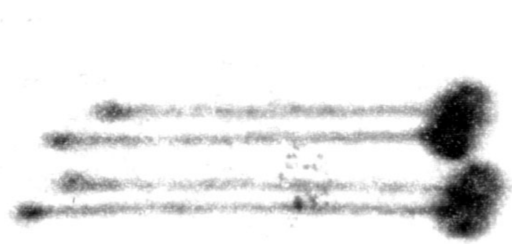


Figure 5b. The four individual drops from a single channel propagate in parallel and with equal velocity (enlarged view from Fig. 5a).

The ink drop volume of the '4× large drop' printhead was measured with a balance. While printing the ink level in the ink container was kept constant at 20 mm below the line of the nozzles. The drop volume data is compiled in Fig. 6. At low printing frequency the total ink drop volume per channel increased to 175 pl. The reduction of ink drop volume beyond 3 kHz for 16 channels printing indicated the onset of a flow restriction within the ink channels. The increased starvation for 126 channels printing revealed a further flow restriction in the ink delivery system outside of the actuator. This could be addressed by widening the ink feed system inside the present printhead. Even with the present restrictions within the ink feed system, however, the total ink drop volume at the maximum printing frequency of 4.9 kHz was essentially the same as that of the '1× large drop' printhead.

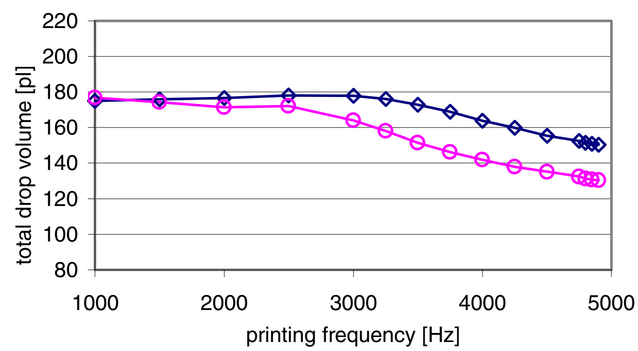


Figure 6. Total drop volume of all four nozzles per one channel as a function of printing frequency, (◊) for 16 channels and (o) for 126 channels printing.

Print Quality

The formation of four drops, propagating in parallel and with the same velocity was expected to produce 'square dots' on the substrate. This was indeed observed when printing with the '4× large drop' printheads. Black oil-based pigment ink was used, the print distance kept at 1 mm and the linear speed was 0.1 m/s. Fig. 7 shows four dots from a 3:3 print pattern, i.e. every third channel printed every third pixel. A low wetting substrate was used for this printout in order to visualize the dot placement clearly. As seen in fig. 7 the four individual drops from each ink channel in fact landed on a square grid, and formed an almost 'square dot' on the substrate.

Printing of 'square dots' on a coated 720dpi paper (HD125) was demonstrated in fig. 8. The 3:3 pattern was printed at 185 dpi at a linear speed of 0.6 m/s. The width of the square dots was 1.06 times the nominal width of a pixel, so that the printed square dots filled the pixel areas well.

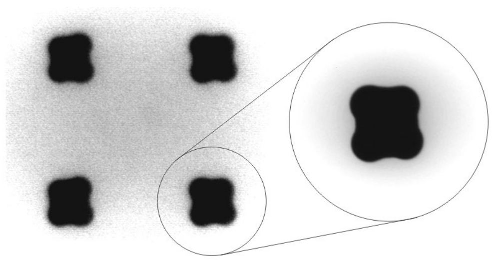


Figure 7. 3:3 pattern printed on a low wetting substrate and an enlarged dot.

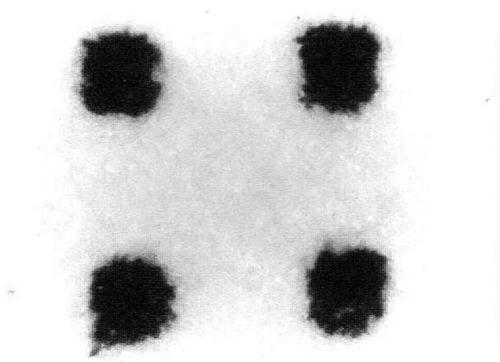
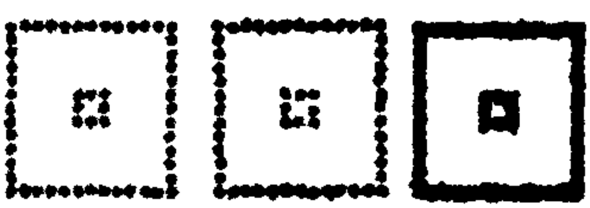


Figure 8. A 3:3 print out on an HD125-720dpi paper. Linear speed was 0.6 m/s. The square dots filled the 185 dpi pixel area well.

The advantage of printing with properly sized square dots became apparent when printing line pattern. Figs. 9a – 9c show line pattern printed on an HD125-720dpi paper with the three different printheads. Specifically the '4× large drop' printhead produced lines of high quality (see Fig. 9c), which was related to the good match between the printed square dot and the pixel area as described above. Straight lines of constant width were produced, and the white pixel in the center of the pattern was well resolved. Due to the low spread of the ink on this coated paper, both the standard XJ126/200, and the '1× large drop' printhead did not fill out the pixel area sufficiently well, so that lines of low quality were produced (see Figs. 9 a, b).



(a) (b) (c)

Figure 9. Line pattern printed onto HD125-720dpi paper with (a) the XJ126/200 in 200 dpi, (b) the '1× large drop' printhead in 185 dpi and (c) the '4× large drop' printhead in 185 dpi resolution.

Mitsubishi produces a glossy paper, IJ-CC-GA125, specifically for usage with the oil-based ink Toyo XS. When printing onto this paper in 185 dpi resolution the square dots from the '4× large drop' printhead considerably overfilled the pixel (the width of the square dot was 1.15 times the pixel width). The lines were too wide and the central white pixel in the test pattern could not be correctly resolved as shown in Fig. 10c. To obtain a better match to this glossy paper the nozzle layout of the '4× large drop' printhead would have to be modified. The present '1× large drop' printhead on the other hand did print the test pattern with a well resolved white central pixel on the glossy paper (see Fig.10b), while the XJ126/200 printhead underfilled the pixel area (see Fig. 10a).

(a) (b) (c)

Figure 10. Line pattern printed onto IJ-CC-GA125 glossy paper with (a) the XJ126/200 in 200 dpi, (b) the '1× large drop' printhead in 185 dpi and (c) the '4× large drop' printhead in 185 dpi resolution.

Optical Density

The formation of 'square dots' was meant to increase the optical density of single pass print pattern. To verify this assumption optical density measurements were conducted. The printouts were printed in a single pass with a 100% print pattern. Print distance was 1 mm, and scan speed 0.1 m/s. Four coated papers were employed: HD115, a 360dpi paper, HD125, a 720 dpi paper, OLT-720, a 720dpi paper, and IJ-CC-GA125 from Mitsubishi. The optical density was measured with a Gretag Macbeth™ SpectroEye™, and the data is compiled in Figure 11.

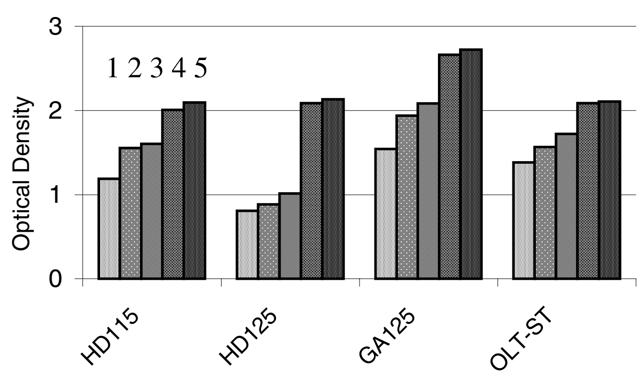


Figure 11. The optical densities of a 100% print pattern on four coated papers as printed with (1) XJ126/200 at 200 dpi, (2) '1× large drop' printhead at 185 dpi, (3) '1× large drop' printhead at 200 dpi, (4) '4× large drop' printhead at 185 dpi, and (5) '4× large drop' printhead at 200 dpi.

As expected the doubled ink drop volume of the '1× large drop' printhead resulted in an increase in optical density as compared to the XJ126/200 printhead. The '4× large drop' printheads provided an additional increase in optical density by the formation of square dots, which filled the pixel areas well. Full coverage of the papers without any remaining white areas was achieved beyond optical densities of 2.0.

Summary and Conclusions

Modified Xaar-type printheads, here referred to as '1× large drop' printheads, were able to produce total drop volumes per channel of more than 150 pl, and maintained stable drop formation.

When equipped with four nozzles per ink channel these '4× large drop' printheads produced four individual ink drops of up to 175 pl total volume, which printed 'square dots' onto the substrate. The present '4× large drop' printhead printed well resolved line pattern with oil-based pigment ink onto HD125/720dpi paper, and achieved an optical density of 2.1 in 185 dpi resolution. On the IJ-CC-GA125 glossy paper an optical density of 2.7 was obtained.

Applications of the large drop printheads are expected in areas as e.g. printing with high optical density on strongly absorbing substrates like card-board, or printing of thick layers of ink for UV-light fastness. 'Square dot' printing appears to be specifically suited for bar-code printing.

References

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Biography

Werner Zapka is currently manager of Advanced Manufacturing Technologies at Xaar Jet, AB. He earned his Ph.D. in physics at the Max-Planck-Institute in Goettingen, Germany, on design and applications of excimer lasers from 1977 to 1980. From there he moved to IBM US and IBM Germany where he engaged himself for 14 years in Manufacturing Research and Development on optical and magnetic data storage, laser processing, opto-acoustic, as well as on semiconductor chip manufacturing, micromechanics and electronic packaging. He holds several patents, has published 40 papers, and obtained 6 IBM Invention Achievement Awards. E-mail: werner.zapka@xaar.se