Increased Inkjet Printing Frequency From 'Offset Channel' Printheads

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Abstract

The request for increased print throughput in inkjet printing can be met by increasing the print frequency, while maintaining high ink drop volumes. A modified ink channel geometry, termed 'offset-channels' is presented, which combines both, short, stiff channel walls and large channel cross sections, respectively. Features of this printhead are high resonance frequencies of the channel walls, and high ink drop volumes up to the highest print frequencies. A Chevron-type version of the offset-channel actuator allows operating the printhead at low driving voltages.

Introduction

In industrial printing applications the throughput capability is often the key requirement. For inkjet printing the task to maximize the printed area per unit time can be addressed in different ways. A figure of merit for throughput capability of all these approaches is the total ink volume delivered by an individual nozzle in unit time.

In a recent publication it was described that the ink drop volume can be doubled as compared to commercial piezo inkjet printheads while only slightly sacrificing printing frequency.[1] Together with the capability to print 'square dots', such a printhead has shown a printing throughput 2.5 times higher than the conventional printhead at 185 dpi. The linear speed of the printhead was 690 mm/s in this application.

Many industrial applications, however, require both a high ink flow through the nozzle and a high linear speed of the printhead at the same time. In the following, the concept for a piezo inkjet actuator design will be presented, which is capable of printing at increased printing frequencies, but with the same ink drop volume as a conventional printhead.

The 'Offset-Channel' Printheads

Xaar's XJ126-200dpi printhead was chosen as test vehicle for this investigation. This commercial piezo printhead with 126 ink channels delivers 80 pl ink drop volume at a maximum print frequency of 5.2 kHz. A schematic view of the actuator is presented in figure 1. The ink channels of 75µm width and 380µm depth are separated by walls of 62µm thickness, which results in a high linear density of 185dpi. The channels are located within the piezo-active PZT material, while the cover material is typically a passive, non-polarized material. Electrodes deposited half way down the channel walls and on both sides of the channel walls allow the application of horizontal electric fields to the vertically polarized channel walls and to induce a shear motion of the wall. With appropriate voltage waveforms applied to the channel walls on both sides of an ink channel, the induced wall motions create acoustic waves inside this ink channel, which lead to the formation of an ink drop at the nozzle plate. The nozzle plate at the front end of the XJ126-200dpi printhead contains nozzles of 50µm diameter. Since neighbouring ink channels share a channel wall, they cannot eject drops at the very same time. In Xaar's 3 cycle printing mode the channels are distinguished as A, B or C channels, all firing with the same printing frequency, but sequentially. Further details on Xaar's printheads are described in the literature.[2-4]

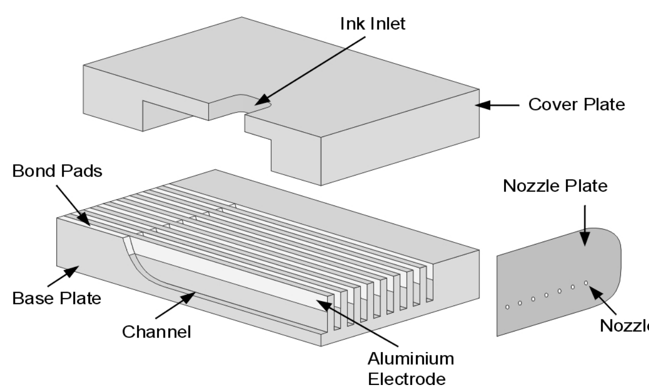

Figure 1. Scheme of an Xaar-type end-shooter printhead

To address the target of increased printing frequency it was intended to stiffen the channel walls and thus to increase the channel walls' resonance frequency. Since the channel pitch had to be kept constant, and the channel width should not be decreased it was decided to reduce the channel wall height from 380µm to 300µm. It is known that ink channels of 75µm width and 300µm depth indeed allow operating at increased printing frequencies, however, at the expense of reduced ink drop volume.

An alternative arrangement of the ink channels, which will be termed 'offset-channels' in the following, overcomes this problem. As shown in figure 2 the ink channels were elongated in an alternating fashion either upwards into the cover wafer or downwards into the piezo-electric base. In this way the height of the movable channel walls could be kept small to yield the desired stiffness of the channel walls, while the alternating elongation of the ink channels yielded enlarged channel cross sections as needed to produce ink drops of high volume.

Specifically, tests were conducted with offset-channel actuators according to figure 2 with the height of the movable part of the channel walls at 300µm. With D_C=300µm and D_B=300µm both, the 'upper' channels, extending into the cover, and the 'lower' channels, extending into the base, have depths of 450µm.

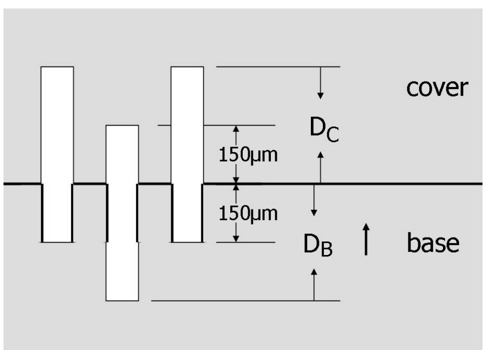

Figure 2. Cross section of an 'offset-channel' actuator. D_C and D_B represent the channel depth in the cover and the base, respectively.

As opposed to the standard XJ126 actuator the offset-channel actuator has channels not only in the base, but also in the cover wafer. Any misplacement of cover to wafer in the assembly process does therefore lead to misalignment at the channel wall glue joint. This would be expected to reduce the stiffness of the channel wall and to affect the resonance performance of the actuator. A test run was therefore carried out with special actuators, in which the alignment of the channel walls in base and cover was gradually varied from –30µm to +30µm. Analysis showed that the actuator resonance performance was constant over a sufficiently large range so that the placement requirement posed no problem for the manufacturing process.

The metal deposition process to produce the electrodes onto the channel walls was kept essentially the same as for the standard actuator. Comparing figures 1 and 2 it becomes obvious that electrodes are produced on the upper half of the channel wall for standard actuators, while the same metal deposition process provides electrodes to the lower half of the movable channel wall for offset-channel actuators. However, the same shear motion of the channel walls could be obtained by simply inverting the polarity of the voltage waveform for the offset-channel actuators.

For the present investigation the offset-channel actuators were equipped with nozzles of 56µm diameter, and drop formation was analyzed with oil-based ink. A figure of merit of the printhead performance is the response curve, which monitors the ink drop velocity for a constant driving voltage as function of the cycle period, i.e. the length of the voltage waveform of one single A, B, or C cycle. The response curve of an offset-channel printhead with channel dimensions as given in figure 2 is shown in figure 3. Only the A-cycles of both the 'upper' and the 'lower' channels are shown here for clarity. The response curves of the B and C cycles are very close to those of their respective A cycles. As intended the resonance, i.e. the maxima of the response curves, at a cycle period of 30.8 µs for both the 'upper' and the 'lower' channels, are well below the corresponding resonance of the standard XJ126-200dpi printhead. This was expected since the movable part of the offset-channel walls is a mere 300µm as compared to the 380µm of the standard printhead.

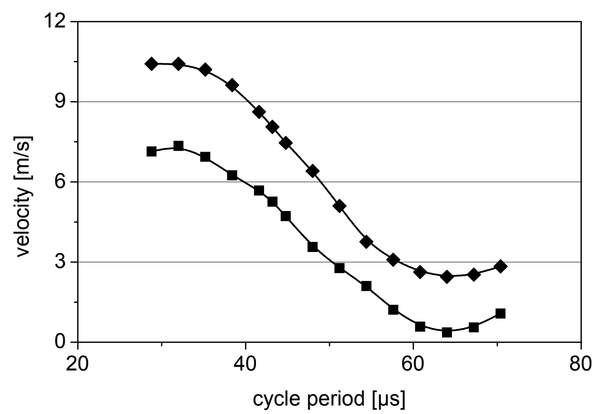

Figure 3. Response curves of an offset-channel printhead with D_C (■) = D_B (◆) = 300 µm

The fact that the upper and lower channels share the same channel walls explains the fact that the maxima of their respective response curves are identical. Remarkable, however, is the difference in efficiency between the upper and the lower channels. In spite of identical cross sectional area the upper channels yield considerably higher ink drop velocities at the same driving voltage.

This higher efficiency of the upper channels was attributed to the higher acoustic reflection coefficient at the rear end of the active ink channel, based on the well-defined rear end of the channel wall in the cover. To further study the difference in efficiency, printheads were built, which comprised ten different groups, each of them with a different combination of channel depths D_C and D_B in cover and base.

With the driving voltage kept constant at 30.7 V, and the cycle period at 41.6 µs the different offset-channel geometries were evaluated regarding their ink drop velocity, ink drop volume, and the kinetic energy of the individual ink drops. In figure 4 the ink drop velocity is plotted as a function of D_C for the upper channels, and as a function of D_B for the lower channels. Beyond a crossing point at 215 µm the ink drops ejected from the upper channels were increasingly faster than those from the lower ones. A similar performance was observed for the ink drop volumes. It should be noted that the upper channels with $D_C > 300$µm deliver higher ink drop volumes than the standard XJ126-200 dpi printhead.

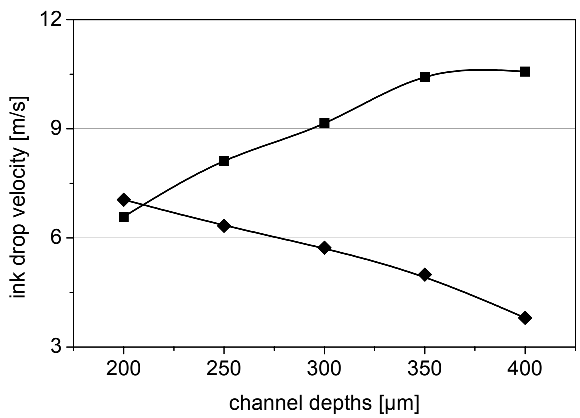

Figure 4. The ink drop velocity as a function of channel depth D_C or D_B for the upper (■) and lower (◆) channels

The kinetic energies of the ink drops from the two extreme channel geometries, namely D_C = 400µm and D_B = 400 µm differ by a factor of 10, though both have the same total channel depth of 550 µm. As explained above, this difference results from the higher acoustic reflection coefficient within the upper ink channel.

Qualified printhead performance, however, requires all channels to print ink drops with the same velocity and volume. Two approaches can be used to obtain this performance. On the one hand a further modification of the channel geometry can be applied,[5] or on the other hand the upper and lower channels can be driven by different voltage amplitudes. The voltage amplitudes needed to provide a constant ink drop velocity of 6 m/s for both the different upper and lower channels, respectively, can be obtained from figure 5.

The measurements of figure 6 were carried out at a printing frequency of 2 kHz and a 35.2 µs cycle period. The data thus demonstrated that the offset-channels of various geometries indeed could produce ink drops of 6 m/s and sufficient volume. However, it remained to be investigated whether the channels could refill sufficiently fast so that high ink drop volumes could be maintained at high printing frequencies, or whether starvation would occur.

Measurements of the ink drop volume were therefore carried out as a function of the printing frequency, with constant driving voltage and the cycle period kept at 35.2 µs. Each channel configuration was driven with that voltage needed to provide a drop velocity of 6 m/s at 2 kHz printing frequency. Both, the smallest upper and lower channels with depth of $D_C = D_B$ = 200µm suffered from strong starvation, showing an essentially identical decrease of the ink drop volume from 75 pl at 2 kHz to 55 pl at 9 kHz printing frequency. With increasing depth D_C and D_B the starvation readily reduced, and for the offset channels with largest depth $D_C = D_B$ = 400µm no starvation was observed up to the highest printing frequency of 9 kHz tested here, as shown in figure 6. The ink drop velocity remained constant for all channel geometries over the entire range of printing frequencies.

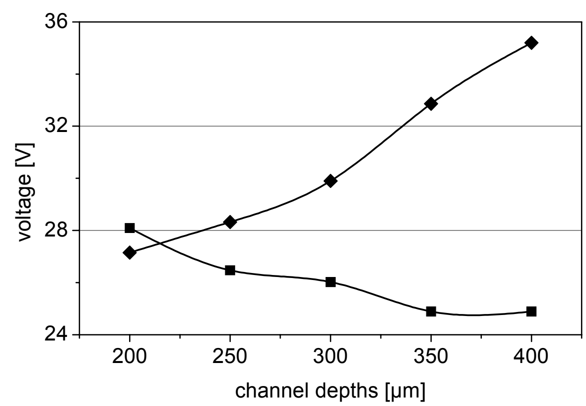

Figure 5. The voltage amplitude required to reach 6 m/s drop velocity versus the channel depth D_C or D_B for the upper (■) and lower (◆) channels

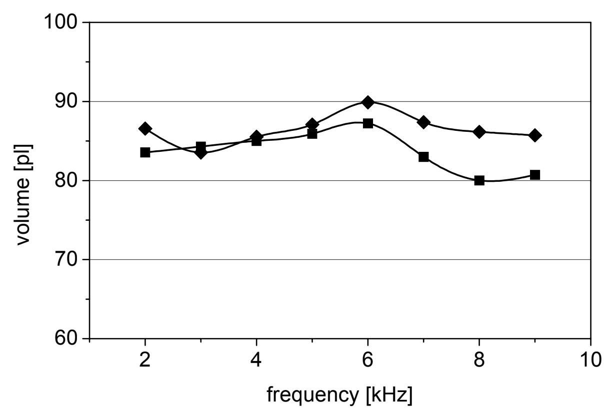

Figure 6. No starvation was observed up to 9 kHz print frequency for both of the offset-channels with large channel depth, $D_C = D_B$ = 400 µm, i.e. the upper (■) and lower (◆) channels, respectively

A disadvantage of the offset-channel printheads with monolithic cantilever design are the relatively high driving voltages for the lower channels. This problem was solved by using the Chevron-design for the offset-channels as sketched in figure 7.

The glue joint between the two oppositely poled PZT materials was positioned at the center of the movable parts of the channel walls, and the movable parts of the channel walls were fully covered with electrodes. Measurements revealed that a Chevron design (according to figure 7) compared with a monolithic design of identical offset-channel depth (see figure 2) yielded highly increased efficiency in drop formation, and allowed to reduce the driving voltage by more than 10 V (see figure 8). The Chevron offset-channel printheads could therefore operate even the lower channels at driving voltages, which were lower than those for standard XJ126-200 dpi printheads.

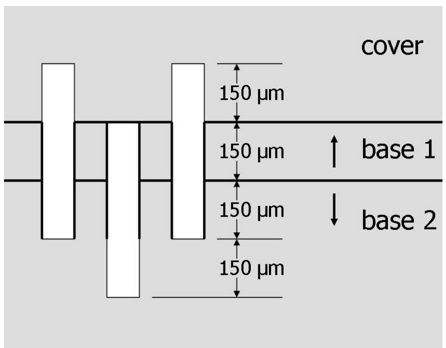

Figure 7. The Chevron version of the offset-channel actuator

Summed up it was possible to operate offset-channel printheads at elevated printing frequencies while maintaining high ink drop volumes and without channel starvation. A Chevron version of the offset-channel printhead further allowed driving the printhead at low voltage levels.

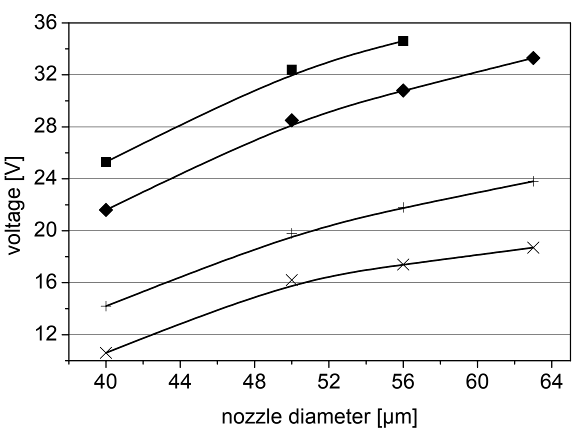

Figure 8.The driving voltages required to obtain ink drop velocities of 6 m/s plotted against the nozzle diameter. Chevron type offset-channel printheads (× upper channel, + lower channel) require strongly reduced driving voltages as compared to their monolithic counterparts (◆ upper channel, ■ lower channel).

Conclusions

Several features are combined in the design of offset-channel actuators and provide advantageous performance. (1) The short and mechanically stiff channel walls yield high resonance frequencies as basis for high printing frequencies. The large channel cross section area provides both, (2) large ink drop volumes and (3) starvation-free printing up to high print frequencies, respectively. (4) The upper channels with well defined acoustic reflection at the rear end of the active length yields highly efficient drop formation, i.e. high drop velocity and volume at low driving voltage. (5) A Chevron version of the offset-channel actuator provides further increased efficiency and thus allows to drive even the lower, inefficient channels at low driving voltage. These investigations represent one example of how modifications to piezo inkjet printheads will enable to further increase their capability and print throughput.

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 Göttingen, 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 44 papers, and obtained 6 IBM Invention Achievement Awards. E-mail: werner.zapka@xaar.se

References

1. W. Zapka, R. Kaack, W. Voit, M. Schulz, M. Zimmermann, L. Levin, W. Ahlemeier, “Large Drop Volumes From Xaar-Type Inkjet Printheads”, IS&T´s NIP 18: 2002 International Conference on Digital Printing Technologies (2002), pp.161-165.
2. H.J. Manning and R.A. Harvey, Xaar Greyscale Technology, Proc. IS&T’s NIP 15, pg. 35-39, (1999).
3. W. Zapka, J. Brünahl, O. Wouters, and M. de Roos, Thermometry Inside Inkjet Actuators, Proc. DPP 2001: Eye on the Future, pg. 392-396, (2001).
4. A. Jorzick, W. Zapka, Real-time Temperature Measurements Inside a Printhead Actuator, Proc. Actuator 2002, pg. 138-140, (2002).
5. to be published