Thermometry Inside Inkjet Actuators

Werner Zapka[1], Jürgen Brünahl[1,2], Onne Wouters[3], Mike de Roos[1]
[1]XaarJet AB, Stockholm, Sweden
[2]Royal Institute of Technology, Condensed Matter Physics
Stockholm, Sweden
[3]University of Groningen, Material Science and Engineering
Groningen, The Netherlands

Abstract

Temperature measurements were conducted inside Xaar-type inkjet actuators. Additional channel walls served as thermometers by way of monitoring the channels' temperature dependent electrical capacity. In this fashion we monitored local temperature differences within the actuators as induced by ink flow or print pattern. We further demonstrated that hybrid actuators comprising high thermally conducting materials can efficiently equalize temperature throughout the actuator. Such is aimed at reducing thermally induced variations of ink drop velocity and volume, and consequently increasing print quality.

Introduction

Xaar develops and produces piezo inkjet printheads, which are based on the shear mode shared wall actuator principle. Well defined voltage waveforms to the piezoelectric walls on both sides of the ink channel induce shear motion of these walls. This results in a specific acoustic wave traveling within the ink channel, and in turn produces the formation of an ink drop. The fluidic parameters of the ink are therefore important parameters for velocity and volume of the ink drops.

Temperature changes within the actuator, which modify the ink's viscosity and surface tension, do therefore cause variations of the ink drop velocity and volume. The viscosity of a typical oil-based ink for example decreases from 11 to 8 mPa s with temperature increase from 30 to 40 °C. If not compensated these viscosity variations would lead to significant changes in drop velocity and volume, 9% and 13%, respectively, as measured with Xaar-type printheads.[1] In consequence these would result in dot placement errors, and dot size deviations during printing, and need to be minimized.

Although piezo-type inkjet printheads are low in power consumption as compared to bubble-jet printheads the actuator heats up during printing. A countermeasure is to appropriately reduce the driving voltage to the channel walls in relation to the temperature in order to keep drop velocity and volume constant. The temperature measurement is typically performed by a thermistor, which is placed outside the actuator. With a well adapted thermal voltage compensation Xaar-type printheads indeed yield high quality printing.

A disadvantage of the thermistor placed outside the actuator is, however, the lack of spatial resolution of the temperature data inside the actuator. Therefore it is not possible to detect and compensate local temperature variations along the row of ink channels.

Local temperature variations can obviously result from odd print pattern, with e.g. heavy duty printing on a number of individual channels only. Dependent on the ink flow within the actuator, however, temperature gradients along the line of ink channels can occur even with even print pattern as will be described below.

In the following we will deal with approaches to minimize thermal effects on print quality, and specifically we will describe a method to measure temperature inside the actuator with local resolution.

A Thermometer Inside a Xaar Inkjet Actuator

The actuator of a Xaar-type printhead is composed of a base plate of piezoelectric material, and an inactive cover plate. Figures 1 and 2 show an overview and a cross section of the ink channels. The base plate, made of PZT material (HD3203) contains a multitude of ink channels, which are closely spaced with a pitch of 137 µm. Channel width and depth are typically 75µm and 380 µm, respectively. Metal electrodes are deposited on the upper half of both sides of the channel walls. The cover plate is glued onto the base plate. It forms the roof of the ink channels, and clamps the top of the channel wall rigidly. A nozzle plate is assembled onto the actuator front surface.

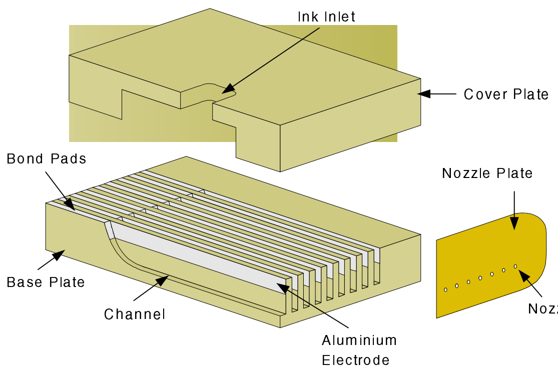

Figure 1. Overview of the inkjet actuator.

Through an opening in the cover wafer ink is fed into the channels. When a voltage is applied to the electrodes on both sides of a channel wall, the horizontal electrical field induces a shear motion of the vertically polarized PZT channel wall. Appropriate temporal voltage waveforms with opposite polarity to both walls of an ink channel, say channel number 3 in figure 2, will cause fast transient increase and decrease of the channel volume. The resulting acoustic wave within the channel gives rise to the ejection of a drop at the nozzle. For further details on voltage waveforms and drop formation we refer to Refs. 2, 3, and 4.

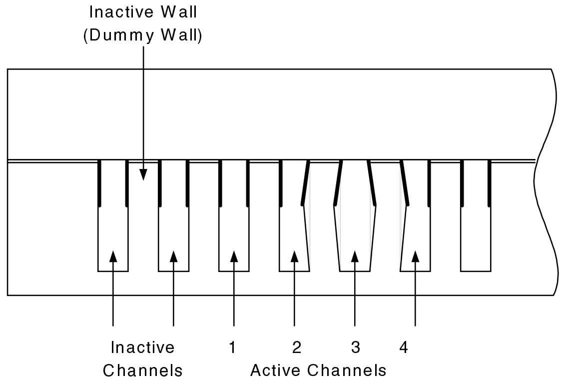

Figure 2. Actuator cross section and 'dummy wall'.

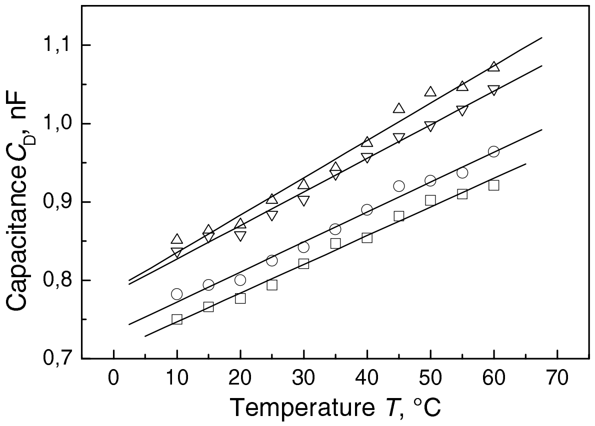

Figure 3. Electrical capacity of individual dummy walls versus temperature.

The actuator design in figure 2 shows two inactive channels outside the row of active channels. These provide the first active channel with symmetric mechanical boundary conditions in the neighbouring channels, as is needed for wall motion. Since the inactive channels are manufactured in the same fashion as the active channels they can be electrically bonded as well. We can therefore electrically connect to the electrodes on both sides of the inactive wall, the 'dummy wall', and sense its electrical capacity. Measured data of electrical capacity versus temperature for dummy walls from different printheads is depicted in figure 3. We observed a strong dependency, which makes the dummy wall's electrical capacity a versatile thermometer. On the other hand we see in fig. 3 that the data of the different dummy walls do not overlap, which we attribute to slight variations in the PZT material, wall thickness etc. This requires calibration of each individual dummy wall thermometer.

Monitoring the 'Dummy Channel's' Electrical Capacity

We chose a voltage divider circuit, shown in figure 4, to monitor the electrical capacity C_D of a dummy wall. A dummy wall was connected in series with an external, discrete capacitor C, which was kept at constant temperature. As input voltage V_{osc} we used a stable AC-signal of 4.0 kHz, with 10 V amplitude. At this frequency we had found least noise in a previous analysis. We found C = 20 nF to be well adapted to the dummy wall's capacities of typically 1 nF to provide an essentially linear, but sensitive output voltage V_1 in the temperature range of interest, 20 to 60 °C.

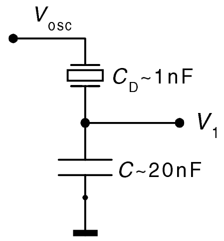

Figure 4. The voltage divider.

A high impedance voltage follower was used to decouple the capacitors C_D and C from the rest of the circuit. With a band-pass filter of 4 kHz resonance frequency and 440 Hz bandpass we reduced noise from the neighbouring channels during printing. The signal was then converted into a DC-signal. A low-pass filter with a cut-off frequency of 500 Hz reduced residual noise, which passed the band-pass filter. The resulting DC-signal could be recorded to monitor temperature changes of the dummy wall.

Calibration of the dummy wall thermometer was carried out in a climate chamber. For the following experiments we used Xaar Jet XJ128 printheads with dummy wall thermometers at both ends of the actuator. We refer to these as 'dummy wall L' at the left-hand side of the actuator, next to active channel 1, and 'dummy channel R' at the right-hand side, respectively. The DC-output voltages for both dummy walls were recorded while the climate chamber temperature was raised in steps of 5 °C. Typical calibration curves for the two dummy walls of a printhead are given in figure 5, indicating the high sensitivity of these dummy wall thermometers.

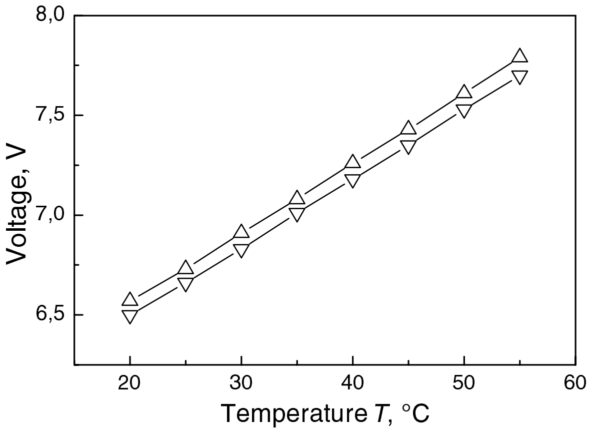

Figure 5. Typical calibration curves of dummy wall thermometers.

Temperature Differences Induced by Ink Flow

In a first experiment we fired an XJ128 printhead dry, i.e. without feeding ink. All 128 channels were fired at 5.5 kHz. Within some 10 minutes the temperature at both dummy walls increased from the original 21 °C room temperature to a saturation temperature of 61 °C, see figure 6. After additional 10 minutes we switched the printhead to firing 'zero signals' at all channels, i.e. firing at a reduced voltage, which will not produce the formation of an ink drop. This resulted in a temperature decrease to 32 °C before the driving voltage to all channels was turned off, and the temperature decreased to the original value. From the essentially total overlap of the voltage signals from both dummy wall thermometers we concluded that the temperature distribution within the actuator was fully symmetrical.

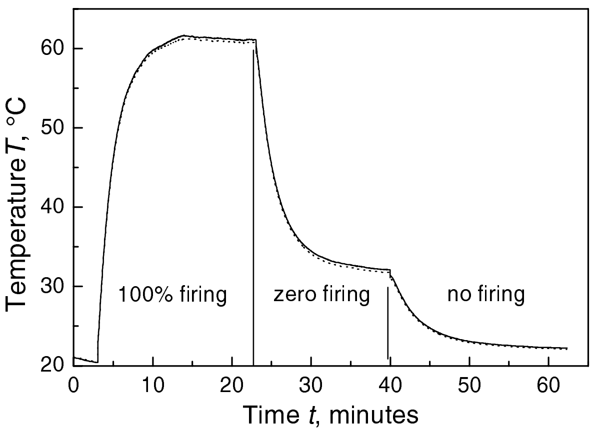

Figure 6. Temperatures at both ends of the actuator when printing without ink.

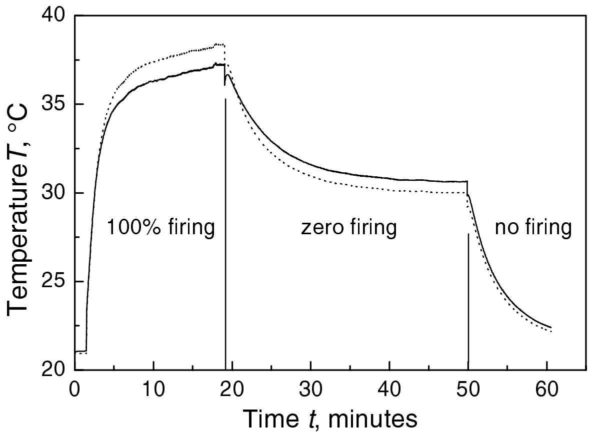

Figure 7. Temperature differences as induced by ink flow.

When we repeated the same experiment with ink fed to the printhead we obtained the temperature development of figure 7. The ink had a twofold effect. On the one hand the saturation temperature with 100% firing was considerably lowered in comparison with 'dry printing' indicating the cooling effect of the ink. On the other hand we observed a temperature difference of some 2 °C at both ends of the actuator. This was due to the ink inlet being located at one side of the actuator, and the ink being heated up within the ink manifold when flowing to the ink channels at the other side of the actuator.

Temperature Differences Induced By Print Pattern

In another set of experiments we investigated the influence of print pattern on the temperature distribution across the actuator. This experiment was conducted without ink flow to the standard XJ128 printhead. This time we used a sequence of 4 non-symmetric print pattern. Measurement data is given in figure 8. The test sequence was started with print pattern 1, firing block A, channels 1 to 32, at the left-hand side of the actuator, with 5.5 kHz while the other channels were fed with 'zero signals'. As a consequence the temperature as measured at dummy wall 1 on the left-hand side of the actuator saturated at 35 °C, while the temperature at the right-hand side of the actuator remained some 3 degrees cooler. During step 2 and 3 of the test sequence we conducted tests with other print parameters, and voltage levels, which were fed to channel blocks B, respectively C, only. We then commenced step 4 of the test sequence, firing of block D, channels 97 to 128, with the same print parameters and voltage levels as used for driving the block A channels in step 1 of the test sequence. After some 10 minutes we observed saturation of the temperatures at both dummy walls. Obviously the temperatures at both ends of the actuator are precisely reversed as compared to step 1 of the test sequence.

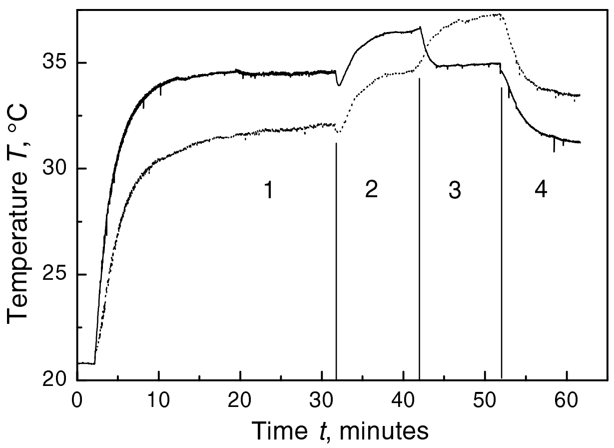

Figure 8. Temperatures at both ends of the actuator for different print pattern.

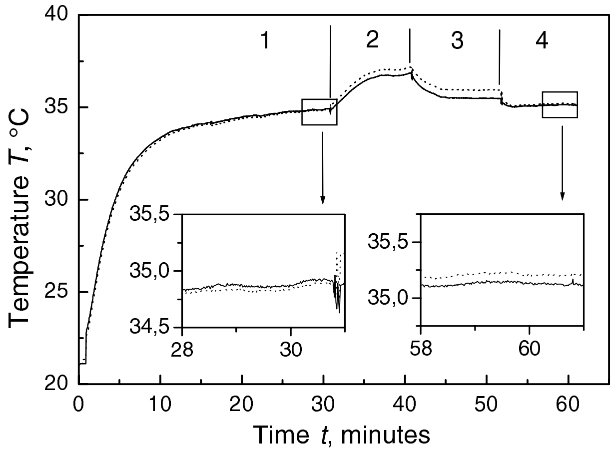

Figure 9. Temperature equilibration by usage of high thermally conducting material.

This was expected since the test was conducted dry, i.e. ink flow effects were excluded. It is of interest that the externally mounted thermistor could not monitor the local temperature difference inside the actuator.

Thermally Conducting Cover Plates

One approach to minimize local temperature variations within the actuator is the usage of material with a high thermal conductivity. We therefore produced XJ128 type printheads with modified actuators. The PZT material that was used as cover plate material was replaced with soft, filled aluminum nitride. The thermal conductivity of 90 $Wm^{-1}K^{-1}$ of this material exceeds that of PZT 75 times. Furthermore the thermal expansion coefficient is matched well to PZT so that the hybrid-actuators could be manufactured and print tested without problem. With such a modified printhead we repeated the 4-step test sequence described previously. As before we performed this experiment without ink to avoid local temperature differences induced by non-symmetric ink flow. When comparing steps 1 and 4 of the test sequence, i.e. when firing only block A and D, respectively, with 5.5 kHz, the measured data in figure 9 showed that the temperature differences between both ends of the actuator reduced to 0.2 °C as compared to the 2.2 °C temperature difference for the printhead with the cover plate from PZT material. This result points out that the cover plate could efficiently dissipate heat across and equalize the temperature throughout the actuator. The increased heat dissipation explained further the slower temperature rise time in figure 9, where it took some 30 minutes to reach saturation. Apart from equalizing temperature within the actuator a cover plate from highly thermal conductive material can obviously facilitate heat dissipation away from the actuator and thus cool the actuator efficiently.

Electronic Temperature Compensation

Xaar-type printheads are delivered with electronic temperature compensation. A thermistor mounted externally to the actuator senses temperature. In case of temperature variations the driving voltage to the channel walls is adjusted to maintain constant drop velocity. Tests with dummy wall thermometers demonstrated that these could be used for electronic compensation as well.
We currently develop another technique to measure the dummy wall capacity in the time interval between consecutive firing pulses. With such a technique it will be possible to use active channel walls as thermometers, and to measure, and compensate local temperature variations throughout the entire actuator.

Conclusion

Inactive ‘dummy walls’ in direct vicinity to the row of active channels allowed to measure temperature with local resolution inside Xaar-type inkjet actuators. This was employed to monitor local temperature differences in the actuator, which were induced by either ink flow or print pattern. It could further demonstrate the efficient heat dissipation and temperature equilibration by the usage of high thermally conducting cover plates for the actuator, which in conclusion minimizes thermal effects on print quality.

References

1. G. Beurer and J. Kretschmer, "Function and Performance of a Shear Mode Piezo Printhead", *IS&T´s NIP 13: International Conference on Digital Printing Technologies 1997*, pp.621-625.
2. H.J. Manning, R.A. Harvey, “Xaar greyscale technology”, *IS&T´s NIP 15: International Conference on Digital Printing Technologies 1999*, pp 35-39.
3. S. Temple et al.: EP277703 (1988).
4. S. Temple et al.: EP278590 (1988).

Biographies

Dr. 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 35 papers, and obtained 6 IBM Invention Achievement Awards. E-mail: werner.zapka@xaar.se

Jürgen Brünahl received his B.S. degree in Microsystem Techologies from the Fachhochschule Kaiserslautern, Germany in 1999. After a traineeship and diploma work at XaarJet AB he began his industrial Ph.D. thesis at the Royal Institute of Technology, Condensed Matter Physics, in cooperation with XaarJet AB, Advanced Manufacturing Technologies.
E-mail: bruenahl@physics.kth.se

Onne Wouters was on a traineeship at XaarJet AB before he commenced his Ph.D. thesis at the University of Groningen, Material Science and Engineering.
E-mail: onnewouters@hotmail.com

Mike de Roos is currently senior electronic engineer at XaarJet AB. He received his M.Sc. degree in Electronics at Chalmers University in Gothenburg, Sweden, in 1989. He worked in IBM Sweden in advanced manufacturing group for 1989-1993. In 1993-1996 he worked as consultant in two software companies. Since 1996 he works at XaarJet AB developing the electronics for the piezoelectric inkjet printheads. He holds two patents in the area of print head technology.
E-mail: mike.de.roos@xaar.se