Crosstalk Study of a Thermal Inkjet Print Head From Real-Time Drop Size and Velocity Measurements

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Abstract

Crosstalk between adjacent inkjet channels is well known in thermal inkjet printheads. Its effect is often undesirable because of resulting changes in drop volume and jet velocity which in turn affect print quality. The characteristics of crosstalk can differ from one print head design to another since it is related to fluid properties and the dynamics of the ink in the interconnected channels. This paper describes an inkjet crosstalk study from realtime drop size and velocity measurements. The interpretation of the measurements was aided with velocity measurements of the ink meniscus obtained with a vibrometer. The results showed that variations in drop volume due to crosstalk were closely related to the oscillations of the meniscus, which were caused by excitations of the other inkjet channels. These variations could be predicted from the crosstalk-induced displacement of the meniscus.

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Introduction

Crosstalk in thermal inkjet printheads refers to the variations in the properties of an individual inkjet when adjacent members from the array of inkjets are also excited. These variations may cause undesirable effects such as drop volume and velocity changes. Since the ink channels share a common manifold, the ink in these channels oscillates as the pressurized bubble ejects the ink to produce a jet.[1] In order to alleviate such a problem, the excitation of individual inkjets is chosen to follow a certain sequence and time delay or to have a large spatial separation so that the oscillations of the ink can decay to a level which does not seriously affect other inkjets. As demands for high dpi and resolution increase, printing speed also has to increase. In this respect the effect of crosstalk must be scrutinized as part of print quality optimization. The study of crosstalk has obvious difficulties. The drop size and velocity need to be measured dynamically, including the oscillations of the ink meniscus. These parameters are generally hard to obtain and may need laborious modifications of the printhead for access.

Using an ink drop sizing instrument and a vibrometer, we have been able to measure the drop size and velocity simultaneously and track the dynamics of the ink meniscus.[2-3] These parameters are essential to the understanding of crosstalk since variation in the properties of an ink drop clearly is related to the oscillations of the ink meniscus.

This paper reports some of the results in a simpified crosstalk study in which only two inkjet channels are examined in each test. Three prototype inkjet printheads of very different designs were tested using the aforementioned instruments. In the next section, the experiment is described. This is followed by a presentation of the properties of the inkjet and the velocity of the meniscus. Finally, the data are correlated and discussed to show the effects of crosstalk and the importance of the displacements of the ink meniscus.

Experiment

The two-part experiment consists of measuring the size and velocity of ink drops and the velocity of the ink meniscus. Three prototype inkjet printheads hereafter referred to as PHI, PH2, and PH4 were used. These printheads had different ink channel designs such that the entrance areas to the heater cavities for PHI, PH2, and PH4 were in the ratios 1, 2, and 4. The layout of a heater element in PHI is shown in Figure 1. These printheads were known to have very different ink refill times and in turn were expected to have different crosstalk behavior. All three printheads were of the topshooter type with nominal 50 μm diameter nozzles and 50 μm thick nozzle plate. For the crosstalk study, two inkjet channels were excited at 0.5 kHz one after the other with a time delay in between. The time delay was varied from 0.1 μs to 500 μs. The low excitation frequency was selected to ensure complete refill of the ink chamber between each excitation cycle. Of the two inkjet channels used in each test, the first one, i.e., the one excited first, acted as the timing reference of the beginning of the excitation sequence. This inkjet channel, for convenience, is referred to as the "clock jet". The second inkjet channel, excited after the time delay from the first, was diagnosed for drop size and velocity and meniscus velocity. This inkjet channel is referred to as the "probe jet". Two excitation sequences were used in the test. The first one had side by side clock and probe jets. For the second one, the two active jets were separated by two dormant inkjet channels. The latter sequence is implemented in some commercial printers.

The first part of the experiment made use of am Aerometrics phase Doppler particle analyzer (PDPA) for ink drop size and velocity measurements. The instrument has been optimized for the measurements of spherical ink drops. In the present experiment, the optical sizing station was 4 mm downstream of the nozzle plate. This separation is much larger than that between the printhead and paper in a printer. However, the location was chosen to provide optical access and more time for ink drops to relax into spheres. The experimental arrangement has been described previously and will not be repeated here.[2] The PDPA delivers measurements of size and velocity pairs, with time stamp, of spherical drops in the inkjet. These data pairs are assigned to histogram bins of widths 1.98 μm for size and 0.29 m/s for velocity. These bin widths hence are also the resolutions of the experiment. An example of the formation of a probe jet with and without the clock jet is shown in Figure 2. The instrument generally is sensitive up to the first three droplets in the inkjet, which are sufficiently spherical. However, in the trailing ink ligaments most of the droplets may be invalidated by the PDPA because of excessive asphericity. Figure 3 shows the size and velocity histograms corresponding to the jet conditions in Figure 2. The diminishing counts for the trailing droplets at low velocity is due to aspherical drops.

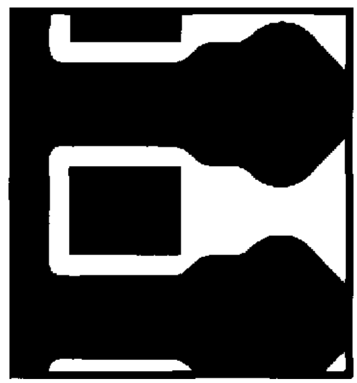

Figure 1. Schematic of one channel of Printhead PH1. The rectangle is the heater outline. The darkened areas away from the heater are for ink confinement

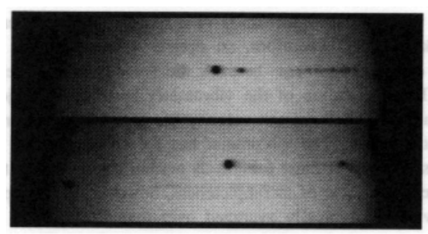

Figure 2. Formation of the inkjet from Printhead PH4; Top: Probe jet only; Bottom: Probe jet excited 120 μs after the clock jet; the clock jet is at extreme left below the probe jet

Having size and velocity information of ink drops is insufficient to unravel the crosstalk effects. Therefore, an optical vibrometer was used in the second part of the experiment to track the velocity of the meniscus at the probe jet. The application of the vibrometer in studying inkjet refill time through monitoring the meniscus velocity has been described previously and is not repeated here.[3] The vibrometer has the advantage that it can probe the meniscus velocity of most printheads nonintrusively and without modifications. There is a facet of incompleteness, however, in this application. It is that the velocity, typically averaged over many scans, 256 in this case, may not be representative of the true average value. The reason is that while the signal is derived from light reflected from the meniscus, it is not consistent from scan to scan. The meniscus, not being an ideal reflector, changes curvature rapidly, causes defocusing of the reflected rays, and degrades the signal. Nevertheless, the velocity signature so obtained does provide useful information of key events such as jet emergence, velocity extrema, zero crossings, and quiescence, etc,. These are important elements in correlating drop size and velocity to inkjet crosstalk. In this respect, the vibrometer provides a unique means of studying the behavior of the ink meniscus with quantitative time dependent data.

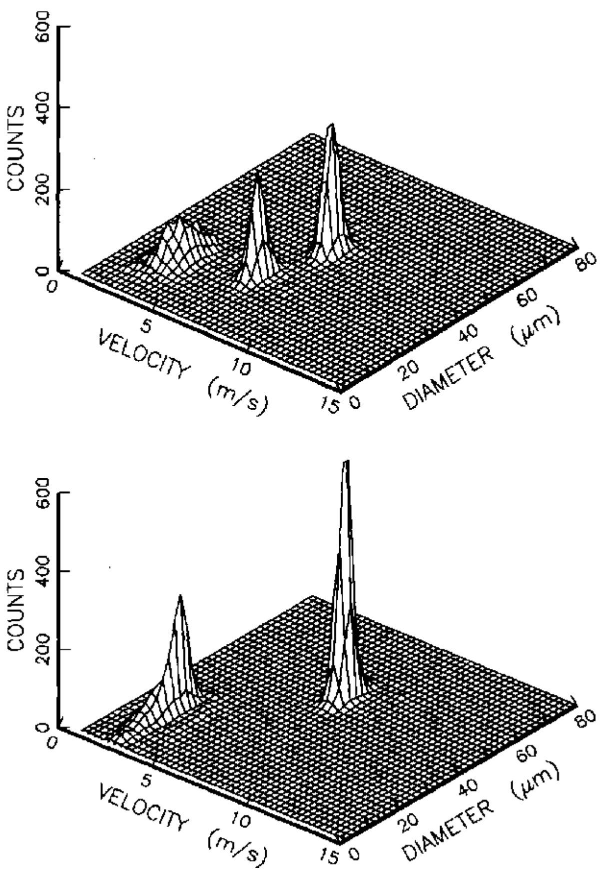

Figure 3. Size and velocity distributions of the probe jet from Printhead PH4; Top: Probe jet only; Bottom: Probe jet excited 120 us after the clock jet

Results and Discussion

The formation of an inkjet while under the crosstalk effect shows structural changes as the time delay between the clock and probe jets is varied. The photograph in Figure 2 shows the jet structure of PH4 at 120 μs crosstalk time delay. It illustrates one of the possible changes in jet formation as crosstalk is present. This is particularly significant as the basic individual jet structures for all three test printheads are similar for the undisturbed probe jet, i.e., when the clock jet is not excited. For the present study about 60% to 80% of the volume of ink at each excitation is delivered by the first one to three droplets in the inkjet. Thus the trailing ink ligaments still carry an appreciable amount of ink although at much lower velocity. Since the printhead operates at 0.5 kHz, the jet is usually steady except at times when size and velocity instabilities appear. Some of these seem to be crosstalk-induced.

Crosstalk-Induced Inkjet Properties

Certain observations in jet structure and velocity can be generalized. When only a solitary droplet followed by the trailing ligaments are present as shown in Figure 2, the drop velocity is usually slower. In this figure, the jet travels from right to left. The position of the single droplet in the bottom of Figure 2 is to the right of the leading drop in the top of the figure. This shows it has slower velocity. The drop volume is usually greater than the sum of the volume of the first two droplets from the undisturbed probe jet. The appearance of one single droplet can occur, for example, when the time delay is as long as 250 μs for PH1, or when it is as short as 10 μs for all three printheads. However, its appearance is limited to a small range of the time delay and only when the velocity of the probe jet meniscus is near the end of the positive part of its oscillation cycle, as will be seen later. Another common crosstalk-induced jet formation consists of three droplets plus the trailing ligaments. When three droplets are distinctly visible, the leading droplet usually has a slightly higher velocity than in the undisturbed case. The total ink volume in the three droplets is less. Complementary to the single droplet case, the triplets appear when the probe jet meniscus is near the end of the negative part of its oscillation cycle.

The ink volume derived from the size measurements of up to three discernible droplets is presented in Figure 4. All three printheads exhibit similar variations with time delay. The volume is usually nearly equal to the undisturbed case at zero time delay. Then it increases to reach a peak between 10 to 30 μs time delay. For the first type of excitation sequence, as the time delay increases further, ink volume decreases, followed by an increase to reach a second peak before decaying to the undisturbed value. For the second type of excitation sequence in which the clock and probe jets are spatially separated by two dormant inkjet channels, these variations are also similar but more moderate.

For all three test printheads, crosstalk does not appear to affect the velocity of the primary drop appreciably. With 0.29 m/s velocity resolution, the change in velocity rarely exceeds 1 m/s except sometimes in the trailing ligaments. The overall effect appears secondary compared to drop volume changes and will not be discussed further.

Crosstalk-Induced Meniscus Velocity

The vibrometer provides additional data for the understanding of drop volume changes. Examples of the normalized meniscus velocity when the clock jet alone is excited are shown in Figure 5. The meniscus within the probe jet nozzle undergoes oscillations when the bubble in the clock jet grows and collapses. The oscillations last approximately three periods. They have complex appearance and definitely are not simple harmonic. The first period has the highest velocity (a positive velocity denotes the meniscus moving away from the heater towards the nozzle exit). The period of the oscillation has two interesting effects. First, it increases with the spatial separation between the clock and probe jets for each test printhead. The amplitude (velocity) also decays with this spatial separation. The second point is that the period of oscillations decreases with the area of the entrance to the heater cavity. Therefore, an inkjet printhead of the type used in this study and with a large entrance area to the heater cavity reduces the overall effects of crosstalk and the length of time when crosstalk is active.

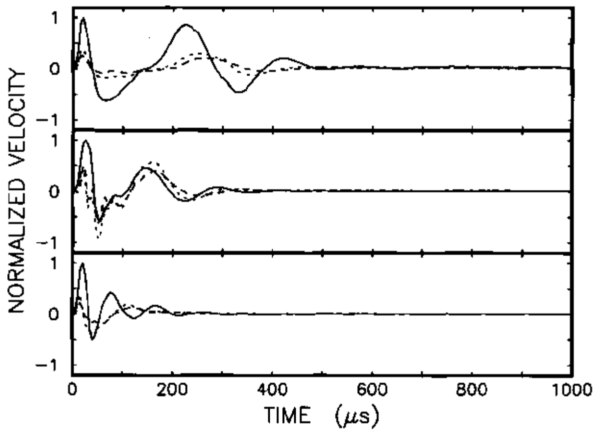

Figure 4. Sum of drop volume from up to the first three droplets in an inkjet. Solid lines represent the first excitation sequence. Dotted lined represent the second excitation sequence. Top: Printhead PHL; Middle: Printhead PH2; Bottom: Printhead PH4

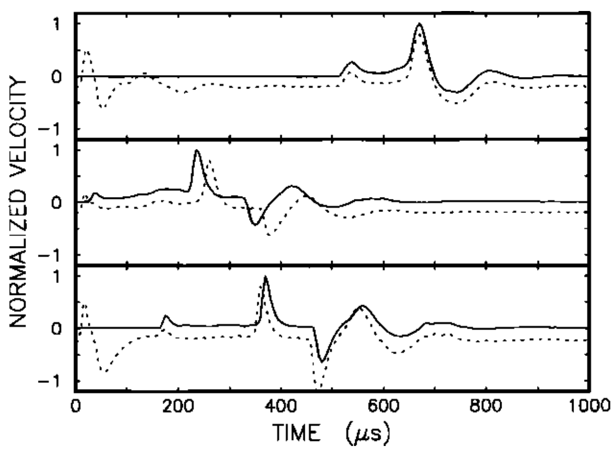

Figure 5. Normalized meniscus velocity at the dormant probe jet when the clock jet is excited. Solid lines represent side by side clock and probe jets (first excitation sequence). Dotted lines represent one dormant inkjet channel between clock and probe jets. Broken lines represent two dormant inkjet channels between clock and probe jets (second excitation sequence). Top: (a) Printhead PH1; Middle: (b) Printhead PH2; Bottom: (c) Printhead PH4

Meniscus Velocity at the Probe Jet

The meniscus velocity at an active probe jet is now examined. Figure 6a shows the meniscus velocity for PH2 at 500 μm delay. This example was chosen to show that meniscus oscillations and the refill sequence can be unrelated events. In this case, meniscus oscillations last about 400 μs. The waveform from 500 μs onwards is caused by drop ejection and the motion of the probe jet meniscus during refill. There appears a positive velocity extremum a short time after the probe jet is excited at 500 μs. This is due to the emergence of the inkjet from within the nozzle. This time is different for the three test printheads. For the case shown in Figure 6a, it is about 32.5 μs and is greater than the time needed for the ink meniscus to traverse the thickness of the nozzle plate, nominally 5 μs in this case. The delayed emergence is attributed to the time required for bubble activation and growth. As the time delay is shortened, the probe jet will emerge while its own meniscus is still undergoing an oscillatory motion because of the influence from the clock jet. This causes an unexpected translation of the entire refill waveform.

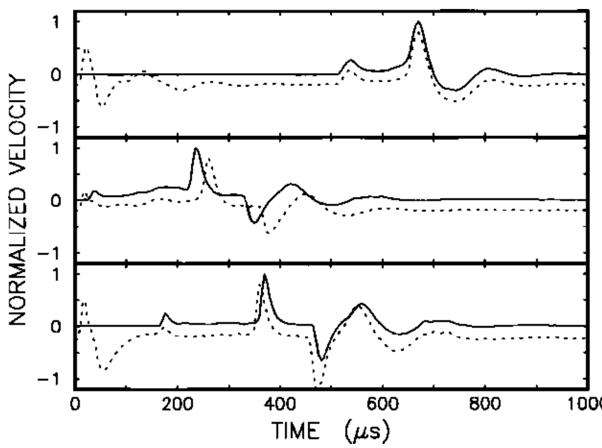

Figure 6. Normalized meniscus velocity at the active probe jet with and without an excited clock jet. Solid lines represent dormant clock jet. Dotted lines represent excited clock jet (curves are vertically offset for clarity). Top: (a) Printhead PH2 with 500 μs time delay; Middle: (b) Printhead PH1 with 20 μs time delay; Bottom: (c) Printhead PH1 with 160 μs time delay

To illustrate the translation of the refill waveform as the clock jet is excited, the meniscus velocities for PH1 at 20 μs and 160 μs are shown in Figure 6b and 6c. At 20 μs time delay, this translation is to lag behind the normal refill waveform by 25 μs, which far exceeds experimental uncertainties. When the delay is 160 μs, this translation is opposite to the previous case. It advances 10 μs ahead of the normal refill waveform. An examination of the meniscus velocity when the probe jet is dormant may help understand this effect. Referring to the meniscus velocity in Figure 5a for PH1 (solid line), it can be seen that at 20 μs time delay the probe meniscus is on the edge of the positive slope of a positive velocity motion which is induced by the clock jet. The meniscus will move away from the heater towards the nozzle. Since ink ejection for PH1 is 20 μs behind the excitation pulse as determined from other data not shown here, the actual ejection in this case is 40 μs after the clock jet channel is excited. At this point, the meniscus at the probe jet channel is near the zero crossing of the velocity curve (Figure 5a) and presumably at the point of maximum advance. Ink ejection at this time can produce oversized drop volumes. Since the appearance of the solitary droplet occurs at this time, it can be understood to be jet formation associated with an overfilled ink cavity. It also explains its velocity decrease described above. The overfilled cavity may also cause the waveform translation since the initiation of refill is determined by the balance of fluid forces. In this case the distribution of fluid after the excitation is also disturbed because of the overfill. Similarly, for the 160 μs delay case, ink ejection will initiate at 180 μs after the excitation pulse, at which time the meniscus is also near the zero crossing, having gone through its first negative velocity journey. The meniscus therefore recedes towards the heater cavity. This results in a reduction in the available ink volume for ejection and hence a smaller drop volume. Again, triplets are formed as a consequence at this time and have a higher velocity because of smaller drop volume.

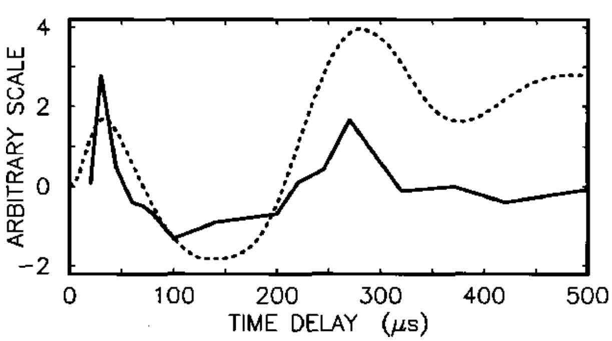

Figure 7. Comparison of drop volume and meniscus displacement computed from integrated meniscus velocity for Printhead PH1. Solid line represents drop volume. Dotted line represents integrated meniscus velocity.

To affirm the above observations, the displacement from the initial position of the probe jet meniscus is obtained from integration of the meniscus velocity. This is done with the knowledge that there will be errors because of the incomplete tracking of meniscus velocity by the vibrometer. An example of the integration for PH1 is shown in Figure 7. The solid line is a replot with adjusted ordinate of the same in the top of Figure 4. The displacement of the probe jet meniscus, represented by the dotted line, increases from zero, the reference value, in the beginning of each excitation cycle. This is followed by maximum and minimum values much like the meniscus velocity. Errors are obvious as the net displacement does not return to zero at long delay times, e.g., 500 μs. All three test printheads show similar behavior after integration. This suggests that most of the mistracking by the vibrometer occurred when the meniscus had a negatave velocity. This could be geometry related for when the meniscus recedes into the heater cavity, the nozzle walls could block some of the reflected rays. The drop volume and ink meniscus displacement characteristics can now be superimposed onto each other as shown in Figure 7. In this graph, 20 μs has been added to the time delay for the drop volume. This quantity represents the delay for the jet to emerge after the excitation pulse. With this translation, there appears striking similarity in the trends of the two graphs. All three test printheads have similar qualitative agreements when analyzed this way. This shows that the variations of the drop volume, obtained from summing the volumes of up to the first three primary droplets in the inkjet, can be partly explained by crosstalk-induced displacement of the meniscus of the probe jet, which modifies the amount of ink available for ejection.

Conclusions

We have tested three printheads with entrance areas to the heater cavity in the ratio 1, 2, and 4. We have also shown that crosstalk in inkjets is related to the oscillations of the meniscus which cause variations in drop volume. The variations are more pronounced as the probe jet is spatially closer to the clock jet. A printhead with larger entrance area to the heater region has a smaller influence from crosstalk, which also is of shorter duration. The variations can be predicted if the velocity of the meniscus is known. In our case, it is determined with an optical vibrometer. Crosstalk can also affect the timing of the meniscus oscillations during ink refill. This could become an extra consideration in printhead design for high speed applications.

References

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