New Advances in Piezoelectric Carbon Printhead Technology

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Abstract

A series of new technologies are described which will enhance printing performance for high demand applications, such as wide format graphic arts printing. Important criteria for this study include: jet density at the nozzle, image quality on the substrate, and total ink throughput.

First we will evaluate if the jet density can be doubled from 50 dpi native to 100 dpi native with a single row of nozzles. We will consider such tradeoffs as drive voltage and drop size. These studies are based on laminate carbon array designs.

Second, we will investigate how hybrid printhead construction, using Silicon MEMS to form the nozzles, will improve image quality. This analysis will include the straightness capability of a large population of nozzles, as well as the importance of nozzle feature location to improving image quality.

Third, we will show how ink throughput is maximized using VersaDrop™ jetting technology. This operating mode will allow the user to select between large and small drop sizes on a pixel-by-pixel basis. This technique provides improved image quality and increased productivity. Additional benefits of the throughput analysis include ink throughput as a function of nozzle packing density and also as a function of power consumption.

Introduction

As digital printing presses strive to meet higher throughput and quality, printhead size and functionality become important differentiators. Increased jet density is a requirement for success and variable drop sizes are desired for the optimization of speed and quality. Drop placement capability as a result of nozzle location and jet trajectory are also critical for enabling single pass printing applications. Grayscale functionality allows the end user to balance the tradeoffs between image quality and throughput. In this paper, we will describe how carbon printhead technology from Dimatix has evolved to meet these challenges.

Optimization of Jet Pitch

Increased jet pitch results in more nozzles per inch. Existing carbon printheads from Dimatix are based on 50 dpi jet arrays. Doubling the nozzle density of these arrays from 50 to 100 dpi is desired, but this increase in nozzle pitch requires a proportional reduction of the area for each pumping chamber. An investigation of pitch variation was begun. The initial testing showed that the jetting performance of the double density arrays would require certain tradeoffs. For example, the chart in Figure 1 shows the sensitivity of drop mass to jet pitch. For a 50% reduction in pumping chamber width, the drop mass was reduced by about 15%. Additional test results shown in Figure 2 suggest that the drive voltage would be increased by 15V as the pumping chamber width is reduced by 50%.

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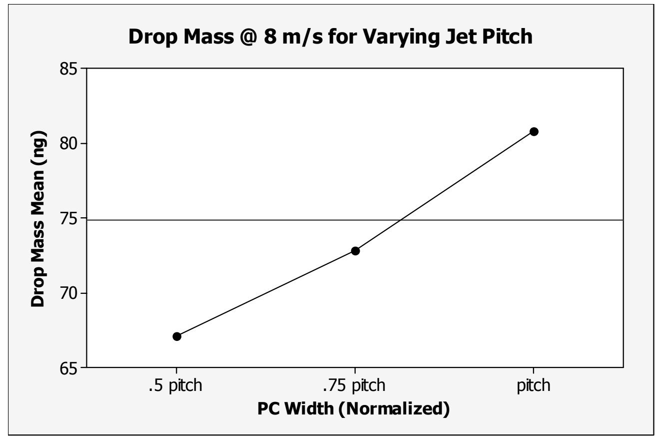

Figure 1: *Sensitivity of Drop Mass to Pumping Chamber Width*

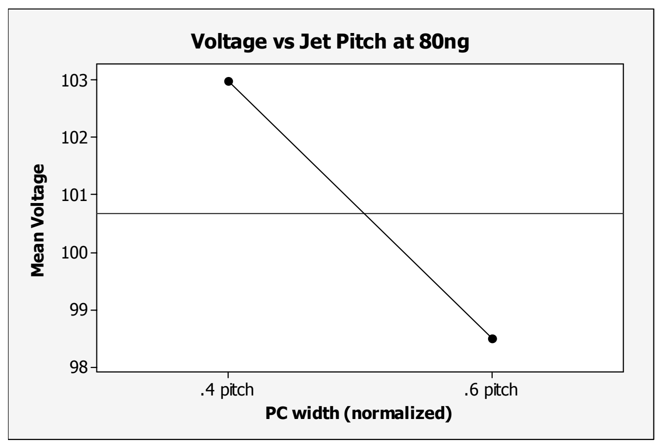

Figure 2: *Sensitivity of Drive Voltage to Pumping Chamber Width*

Though some challenges were identified, these initial results suggested that more investigation was warranted on double density arrays. A comprehensive study was performed to optimize the performance of the double density array. Important variables included pumping chamber dimensions, PZT dimensions, ground/electrode patterns, flow passages, and nozzle fabrication techniques. Important outputs included straightness, uniformity and sustainability over a series of inks and drop sizes.

After several iterations, a new design emerged. The following charts summarize the performance of the optimized 100 dpi design (Q256/30) by comparing it to a previous 50 dpi design (SE-128). Both designs are targeted to produce a native drop of 30ng at a desired velocity of 8 m/s. The operating range of these printheads ranges from 0 to 40 kHz continuously.

In Figure 3, the drop mass and drop velocity are shown, as a function of drive voltage for both printhead designs. It is interesting to note that the 30 ng, 8 m/s design target is achieved by both designs at the same voltage, despite the fact that the Q256 has twice as many jets in the same space allotment.

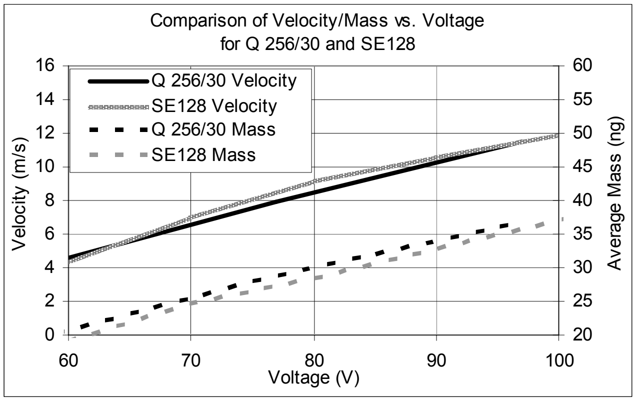

***Figure 3:** Mass and Velocity vs. Voltage for SE-128 (50 dpi) and Q256/30 (100 dpi) designs*

Additional data comparing Q256/30 with SE-128 includes the frequency response data shown in Figure 4. Though the two devices have different peak frequencies, the overall envelope is similar through 40 kHz operation. This will permit a similar range of use for the Q256 as compared with other 30ng printheads, while the increased jet density will allow users to increase the number of jets or reduce carriage size.

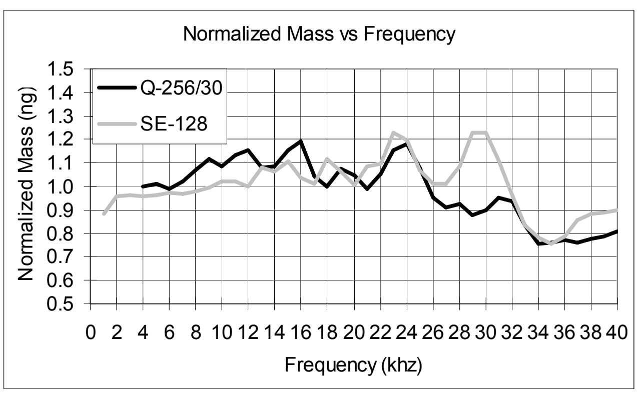

***Figure 4:** Drop Mass vs Frequency for Q250/30 and SE-128*

Silicon MEMS Nozzle Technology

There are many advantages in this design of using a silicon MEMS based nozzle plate. First is the resulting precision and uniformity of the MEMS nozzle array. Feature size and location as defined by the MEMS process are highly capable against the required specs for ink jet components. Feature size is important for jet velocity and drop size uniformity. Feature location is an important contributor to drop placement accuracy.

Another important component of drop placement accuracy is drop trajectory, which is a result of the nozzle fabrication process. The straightness capability of silicon processing is excellent with respect to both nozzle location and drop trajectory. The data is shown in Figure 5 for drop placement error and is inclusive of both nozzle location and drop trajectory error.

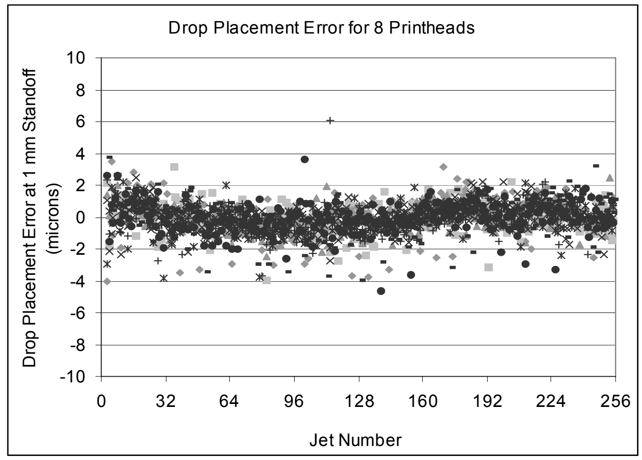

***Figure 5**: Straightness of 8 printheads at 1mm standoff*

Another important benefit of the silicon MEMS nozzle design is the opportunity to incorporate additional features within the nozzle plate. In previous designs, multiple laminate parts were used to create the flow passages needed to pass the ink from the pumping chamber to the nozzle. These laminate parts were mechanically aligned and bonded with glue. In the MEMS nozzle design, several parts can be eliminated and replaced with added silicon functionality. These features have the benefit of wafer based alignment techniques and silicon-to-silicon bonding methods. The precision and repeatability of this design allows for tight tolerances on the most critical of outputs. The SEM photograph in Figure 6 is a view of two of the layers in the MEMS nozzle structure. The MEMS process is an enabling technology for higher pitch jetting assemblies.

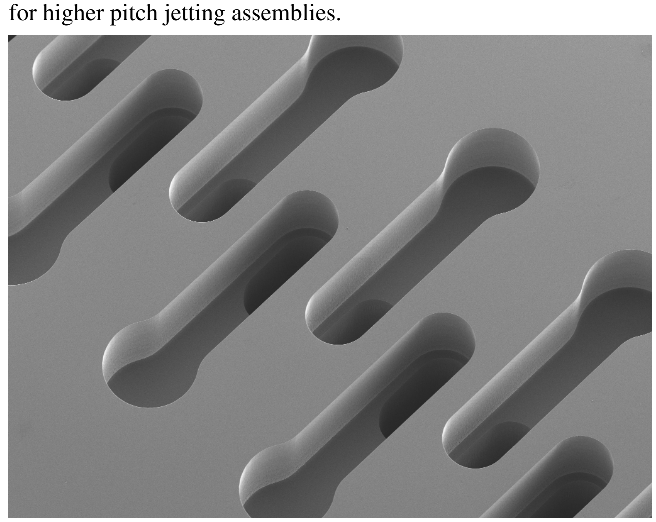

***Figure 6:** SEM photograph of MEMS nozzle plate(entrance side)*

VersaDrop™ Technology

VersaDrop™ technology takes advantage of the inherent high frequency response of FUJIFILM Dimatix hybrid ink jet designs to offer flexible and versatile printhead operation. The defining characteristic of VersaDrop™ is the non-resonant excitation of the piezoelectric element using multiple waveform segments with variable amplitude to pump metered amounts of ink into a single drop before the ligament detaches from the nozzle. This capability can be exploited to produce variable size drops and accommodate a broader range of jetted fluid properties with no compromise in jetting productivity.

The image in Figure 7 shows the output of a printhead using VersaDrop™ technology. Near the top of the picture, six nozzles are barely visible. At the bottom of the picture are the six drops that originated from each of the nozzles. Because each channel in the printhead can be addressed with a different waveform, these drops are being generated at three distinct drop sizes.

In this image, the first two drops are formed at the native, 30 ng, drop size. The second two drops are formed at 50 ng drop size and the largest two drops are 80 ng. It is important to note that all drops are traveling at the same velocity as they leave the nozzle plane, ensuring that the drop placement on the substrate will be achieved with high accuracy. The drops are about 0.5 mm from the nozzle.

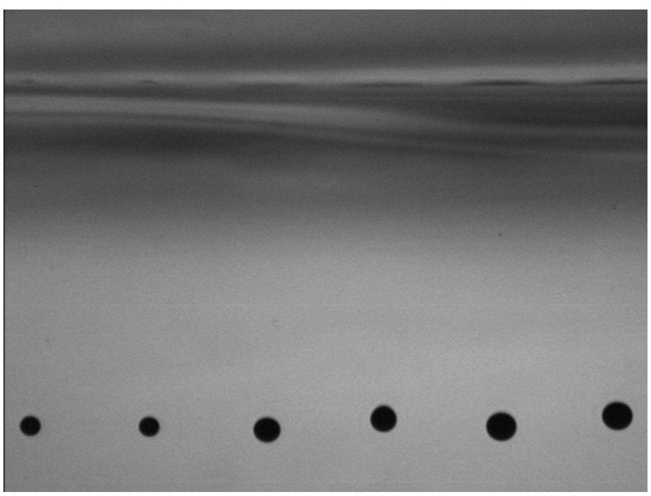

Figure 7: *Variable drop sizes resulting from VersaDrop™ waveforms*

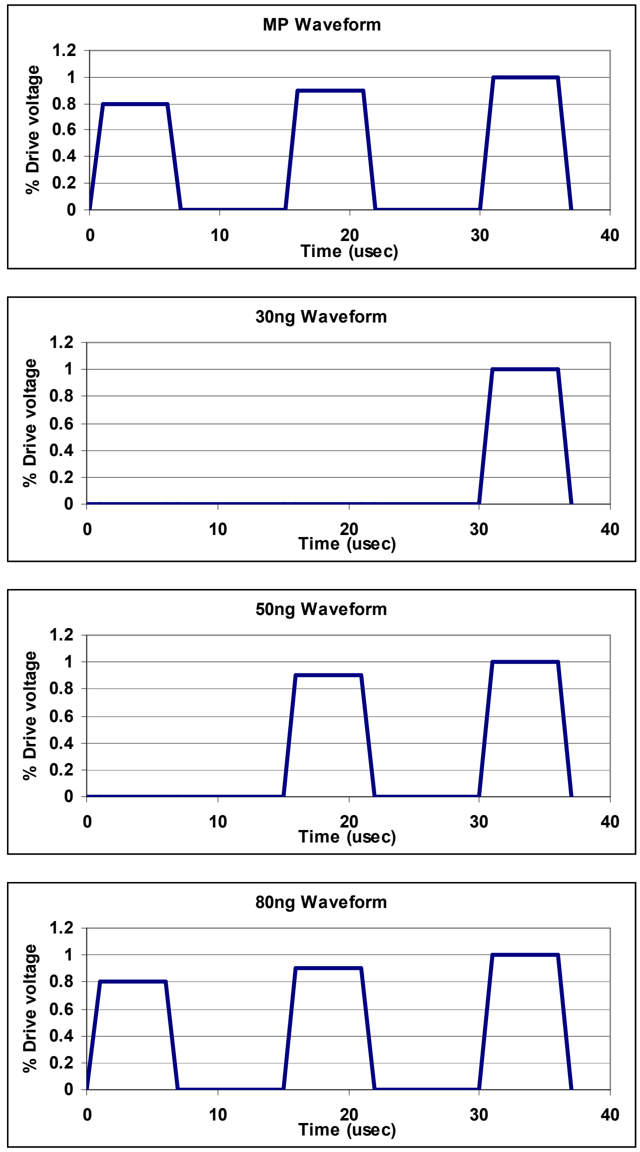

Figure 8A-D: Example of VersaDrop™ waveform with 30, 50, and 80ng component waveforms.

Waveform structure

The ability to print 4 level grayscale with pixel-by-pixel addressability is the result of careful waveform crafting. In this simple example, three drop sizes are used: 30ng, 50ng and 80ng. The 30ng drop is formed by a single trapezoidal pulse. The 50ng drop uses two pulses and the 80ng is formed with three pulses. In order to select drop sizes on a pixel by pixel basis, each of the three required pulses are built into a single waveform, as shown in Figure 8. At any given pixel, only the pulses which result in the desired drop size will be applied.

This example is intended to show how the versatility of VersaDrop™ allows the user to tailor a waveform for his own application. With its arbitrary waveform shapes and the ability to choose any desired section or combination of sections, the exact requirements for each printing application can be addressed. This allows far more flexibility than resonant multipulse functionality achieved with other designs.

Drop Formation and Velocity

The advantages of VersaDrop™ printing are most exemplified by the unified drop formation and consistent velocities that can be achieved. For high quality production printing, the shape and location of the drop on the substrate are the critical parameters to image quality. Using VersaDrop™ printing, we are able to build up large drops at the nozzle, which provides for rounder drops in flight. This is illustrated by the drops in Figure 7, all three sizes are nicely formed as they leave the nozzle plane.

In addition, because we can independently control the voltage associated with each individual pulse, we can ensure that all 3 drop sizes will have the same time of flight velocity. This is also illustrated in Figure 7, where all three drop sizes have traveled the same distance from the nozzle, in the time since the pulse train was initiated.

Other advantages of VersaDrop™ include the opportunity to reduce satellite formation by focusing more ink into the drop, to create round drops by building them at the nozzle plate, and to maintain velocity uniformity by varying the voltage at which each drive pulse is applied.

VersaDrop™ in Application Space

To understand the benefits of VersaDrop™ printing in a production environment, one needs to consider the tradeoffs between print resolution and print speed. High quality graphics require high resolution printing, which means very small drops are placed on very small pixels. The need for precision can reduce carriage speeds. High speed printing is achieved using large drops and large pixels. Carriage speeds are higher because the number of drops required is lower and the tolerances needed for image quality are more forgiving. The differences between high and low resolution printing conditions are shown schematically in Figures 9A and 9B.

Now consider the versatility of the VersaDrop™ printing method. The availability of a large drop for filling the pixel allows for a low-resolution grid. However, fine details and continuous tone can be achieved by selection of the medium or small drop on a pixel-by-pixel basis, as shown schematically in Figure 9C. Waveform selection is achieved using the three pulse method described in Figure 8 above.

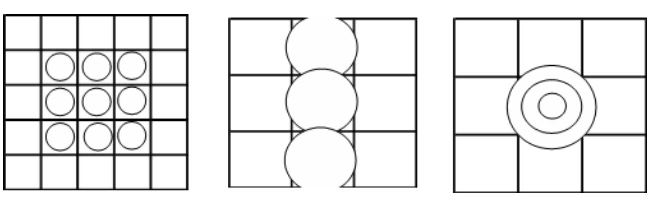

Figure 9A,B,C: Schematic of high resolution, low resolution and VersaDrop™ printing grids.

VersaDrop™ Productivity

The productivity for the three waveforms in the example above is shown in Figure 10, as the product of drop size and jetting frequency (ng-kHz). As the number of pulses required to create the drop decrease, the time available to build the waveform is reduced, and the max frequency achievable increases. Therefore, the native drop size is able to achieve the same productivity as the larger three pulse drop.

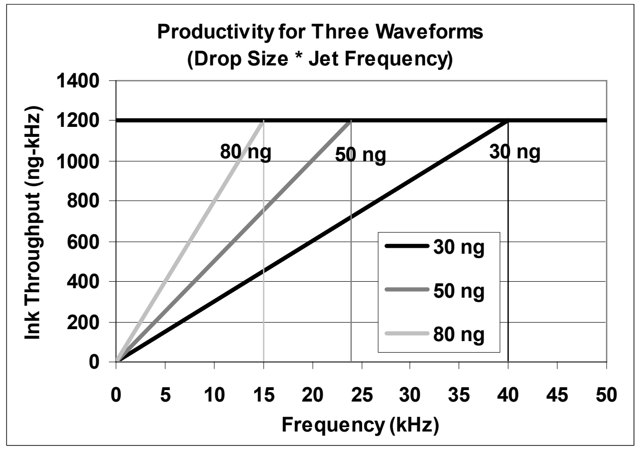

Figure 10: Ink throughput for three drop sizes

Conclusion

We have described a new hybrid printhead design with 100 nozzles per inch which uses silicon MEMS to construct the nozzle assembly. This printhead has been designed and tested with VersaDrop™ waveforms to provide the most versatile print engine possible. Use of the VersaDrop™ printing technology has the potential to improve image quality while maintaining production print speeds. Successful use of VersaDrop™ technology does require careful waveform crafting, which includes interactions between the printhead and ink. When tailored for a specific application space, VersaDrop™ printing allows the user additional flexibility to optimize printing. By using arbitrary wave shaping, variable drop selection, excellent velocity uniformity, and improved drop formation, higher quality output can be achieved.

Author Biography

Marlene McDonald received her BA in Engineering Sciences from Dartmouth College and her MSME in Fluid Mechanics from the University of Massachusetts at Amherst. Since 1994, she has worked as a development engineer at FUJIFILM Dimatix in Lebanon, NH. She has focused on computational modeling, jet design, and new product development.