Production Digital Fabrication System using the Dimatix Q-Class Printhead

William A. Buskirk, ImTech, Inc. Corvallis, OR, USA

Abstract

The Q-Class printheads are the newest printheads from Fujifilm Dimatix. Due to their silicon orifice plate, they provide improved drop placement accuracy per cost over earlier printheads. These printheads are capable of jetting fluids with a wide range of drop volumes. A new system for generating patterns for a high volume production masking application was developed using the Q-Class printheads. The accuracy of drop placement, feature definition and the throughput of this system will be disclosed. The architecture of the deposition system, which uses new drive electronics developed by ImTech, Inc. and mechanism developed by Korvis Automation, Inc. will be described. During development many practical implementation challenges were encountered. The most significant of these will be identified along with their solutions.

Introduction

The use of ink jet printing to directly create electronic components and circuits has been contemplated for many years. The state of the art in commercially available ink jet printheads is 1 pL drops, corresponding to approximately 10 um dots when printed on a substrate. Integrated circuit technology is now using features that are significantly below 1 um and it is clear that inkjet printing will not be used to create circuits at these resolutions however, there are many applications where the resolutions achievable by inkjet printing can be applied. One of the significant challenges of using inkjet printing in electronics is in creating the precise patterns required. The detail that can be achieved is a function of the interaction between the fluid being jetted and the substrate on which it is being deposited, and the accuracy of the placement of drops on the substrate. Considerable effort is being expended by printhead manufacturers to improve the consistency and accuracy of their printhead product line.

Dimatix introduced its new Q-Class printhead in 2009. With its small size, high resolution nozzle spacing and MEMS orifice plate it is advertised to improve throughput and enhance printing performance. [1] When compared to the specifications of the Galaxy printhead, it appears that the Q-Class printhead will provide more accurate drop placement. This paper will explore the actual measured results of the Galaxy and Q-Class printheads when applied to the same application.

The Application

ImTech, Inc. and Korvis Automation, Inc. have been working together on an application in printed electronics where inkjet is being used to create a pattern on a smooth non-porous substrate with 70 um width lines and spaces. Full coverage of the printed area and edge acuity of lines are critical parameters that must be met. Initially Galaxy printheads were selected for the application and provided performance at the edge of acceptability. Q-Class printheads are being evaluated to determine if they will provide a more optimal solution.

Printheads

The Basic specifications for the Galaxy and Q-Class printheads are similar although their construction is very different. (Table 1) The Galaxy printheads are constructed of two 128 channel assemblies that are connected together through the orifice plate to provide one row of 256 nozzles. Each of the 128 channel assemblies is constructed of two rows of 64 Piezo actuators, with 0.040 inch spacing, assembled back to back, and offset from each other by 0.020 inches. The 128 nozzle assemblies are positioned side by side and offset from each other by 0.010 inches providing an assembly of 256 nozzles with 0.010 inch pitch (100 dpi).

Table 1, Printhead Specifications

Parameter	Galaxy JA 256/30, 50, 80	Q-Class QS-256/30
Nozzles	256	256
Native dot pitch (dpi)	100	100
Drop volume (pL)	28, 50 or 80	30 to 80
Drop Velocity (m/sec)	8	8
Drop size variation, 1 sigma (%)	5	
Drop Velocity variation, 1 sigma (%)	5	5
Jet straightness, 1 sigma (mrad)	5	1.5
Jetting Assembly size (w x l x h, mm)	25 x 102 x 102	8 x 117 x 71
Number of PZT elements	4	2
Variable drop levels	1	1 to 4
Fluid viscosities (cP)	8 to 20	8 to 20
Operating Temperature max (Deg C)	90	90
Operating Frequency max (kHz(@pL))	20	33@30 12.5@80
Orifice Plate	Stainless Steel	Silicon MEMS

The Q-Class printhead assembly has twice the dot pitch as those used in the Galaxy printhead, two rows of 128 channels with 0.020 inch spacing offset from each other by 0.010 inches. Only one assembly is required to provide 256 nozzles at 100 dpi. The ink path for each nozzle in the Q-Class printhead follows a shorter and simpler path than on the Galaxy and the orifice plate on the Q-

Class printhead is constructed from silicon using MEMS technology providing better drop directionality control over the Galaxy's stainless steel orifice plate. The jet straightness specification for the Q-Class printhead has one third the variation of the Galaxy printhead. The Q-Class printhead has several other advantages: it is one third as wide as the Galaxy printhead allowing much smaller assemblies when using multiple head arrays, it has the Dimatix VersaDrop capability that allows a wide drop variation on a nozzle by nozzle and drop by drop basis, and it is available at a much lower price.

Printing System

For this application the printheads were fixed in position firing downward and the substrate was moved under the printheads in a direction perpendicular to the nozzle row (x-axis motion). The required print width was longer than the width of a printhead and two printheads were positioned with the last nozzle of one printhead overlapping the first nozzle of the next printhead. (Figure 1) Mechanical adjustments were provided to allow the y-axis position (nozzle overlap) and theta alignment between the printheads to be fine tuned. The application required printing at a resolution that was finer that the native pitch of the printheads and the substrate position was incremented in the y-axis with sub-nozzle resolution steps between each pass. Motion stages were used with resolution and repeatability of 0.2 um and 1.0 um respectively. Systematic variations in drop trajectory that were related to the internal construction of the printhead were eliminated by providing separate timing signals for each of the PZT elements in each printhead. In the case of the Galaxy printhead, four independent firing signals were provided and in the case of the Q-Class printhead, two independent signals were provided. These signals allowed adjustment of the firing location of each PZT element in the x direction at the pitch of the encoder signal from the process direction stage (0.2 um).

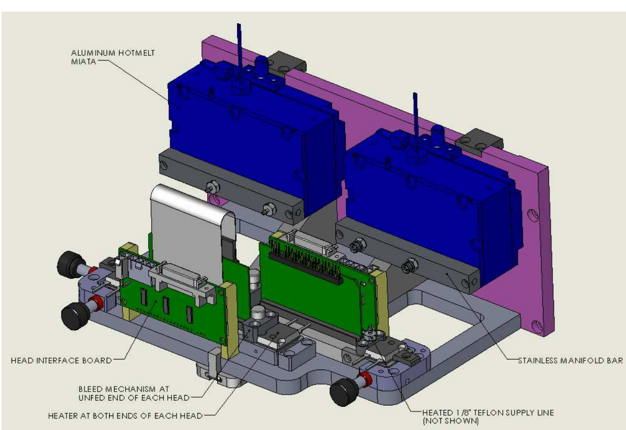

Figure 1: Printhead mounting configuration

The fluid used in the comparison test was a hot melt material with a phase change temperature between 60 and 70 deg C. Fluid was pumped from a main reservoir to a Dimatix Miata lung and then to one end of the printhead. The second port on the printhead was used for the initial priming and sealed while printing. The entire ink supply system was operated at 80 deg C and the printheads were held at that temperature +/- 1 deg. Nozzle pressure was held at negative 0.5 to 1.0 inches of water. Printhead to substrate distance was set at 0.3 mm.

Unfortunately, it was not possible to test the printheads in the same system. The stages used for the Galaxy printheads ware capable of moving at 600 mm/sec while printing with the Q-Class printheads was done between 250 and 400 mm/sec. The Q-Class printheads were fired using a system developed by ImTech. This controller was developed to provide a simple method to control Q-Class printheads. The Galaxy printheads were tested using another controller with similar timing capabilities.

The Q-Class printhead has the ability to create a range of drop volumes from one printhead model. During the normal drop firing time the PZT can be energized with one to four pulses of electrical energy. Each pulse pushes fluid out of the orifice before the tail of the drop separates from the printhead creating a single merged drop. (Figure 2) Each nozzle in the printhead can be controlled independently in terms of which pulses in the wave form are applied to its drop. This allows up to four tunable levels of grey scale to be jetted from each nozzle. In the application being discussed here full grey scale capability was not required and for all of our Q-Class testing the same pulse shape was used for all nozzles and all rows in each print pass. The fire pulse shape was optimized to provide the desired drop volume and velocity for the fluid being jetted was developed by varying the pulse shape parameters. The impact of a sub drop catching up to and merging with the main drop can be seen as dumbbell shaped drops. (Figure 3) At the extreme drops were tuned to eliminate the tail but they had unacceptably low drop velocities (around 3 m/sec). (Figure 4) The Galaxy printheads do not have VersaDrop capability and were fired with a single electrical pulse for each drop.

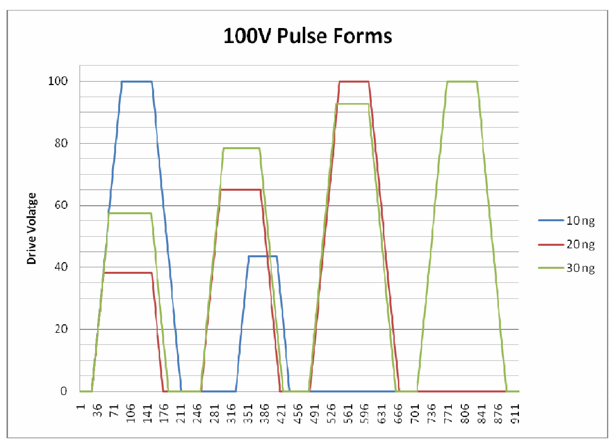

Figure 2: Examples of fire pulse shapes

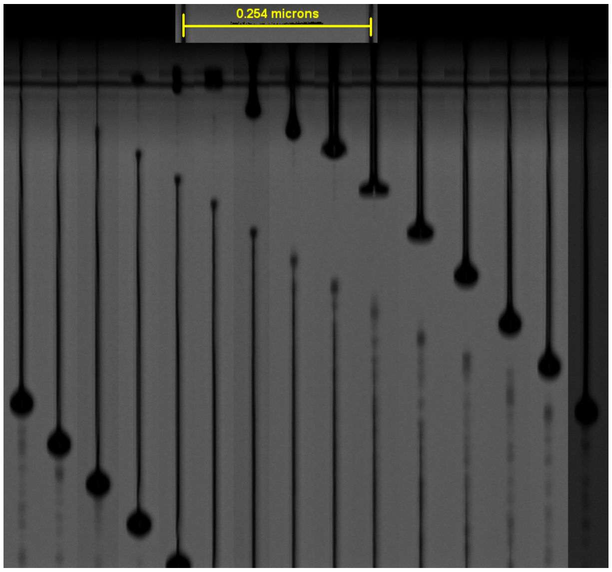

Figure 3: Q-Class Versadrop print mode

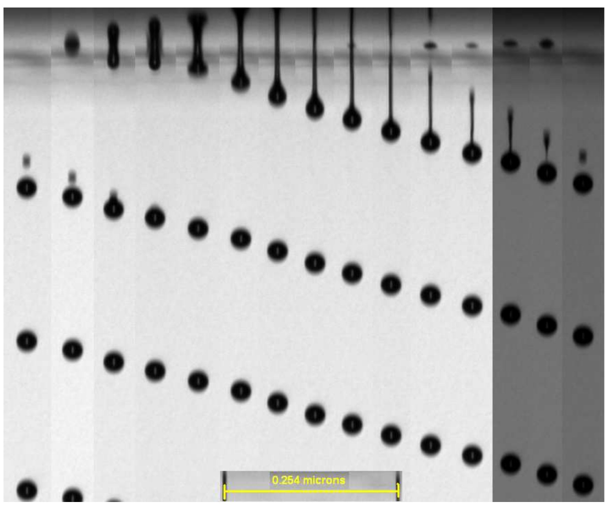

Figure 4: Low velocity drops with no tails

The print pattern used for drop placement accuracy testing consisted of a single pass under the printheads with all nozzles from one PZT firing on approximately a 0.01 inch x-axis pitch. The substrate was then moved to an inspection station where it was placed on a stage with 0.2 um resolution and 1.0 um repeatability, passed under a vision system with 2.0 um pixels and the centroid of every dot was measured. This data was analyzed using Octave, a shareware data analysis program. An average X, Y and theta error was calculated for the entire image and subtracted from each point resulting in an error vector for each point. A chrome glass mask was used as a reference to determine the error that was introduced by the measurement system which was below 0.8 um. (Figure 5)

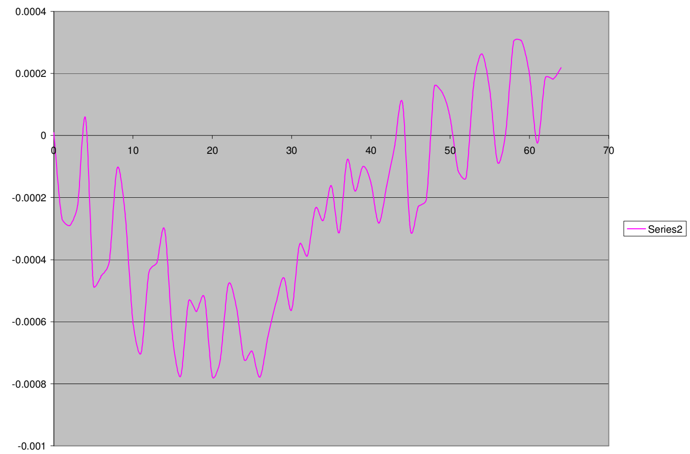

Figure5:System error measured with a chrome glass mask

Results

An example of a full printhead dot placement data set is shown in Figure 6. A magnified view of the data taken from one PZT of a Galaxy test is shown in Figure 7 and of one PZT of a Q-Class test is shown in Figure 8 at the same magnification. It should be noted that there are twice as many nozzles in the Q-Class data since its PZT banks have twice the dot pitch as those in the Galaxy printhead. The RMS error in x and y for the Galaxy printhead is 1.4 um and 2.3 um with standard deviations of 1.4 um and 1.7 um. For the Q-Class printhead the RMS error was 1.2 um and 1.9 um with standard deviations of 1.2 um and 1.9 um.

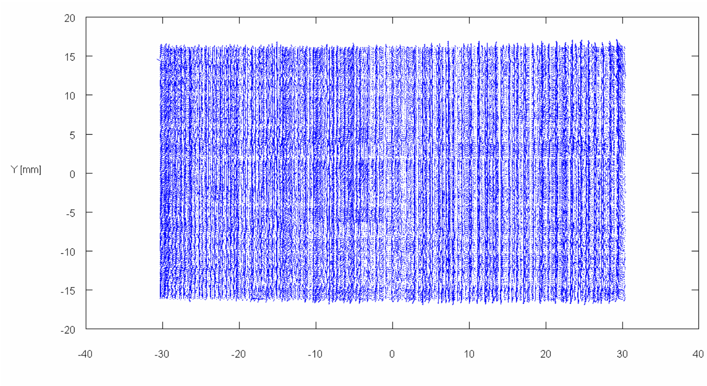

Figure 6: Example of a full drop placement data set.

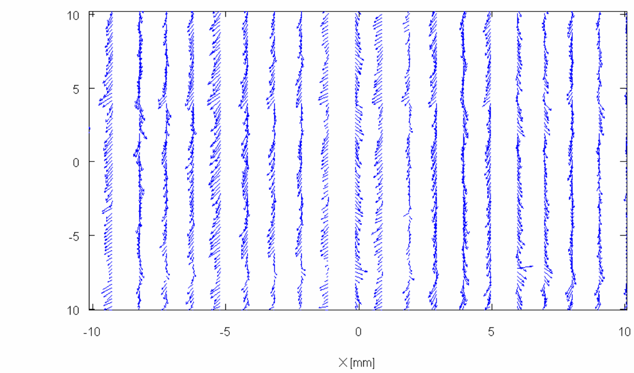

Figure 7: Magnified Galaxy Drop Placement Data

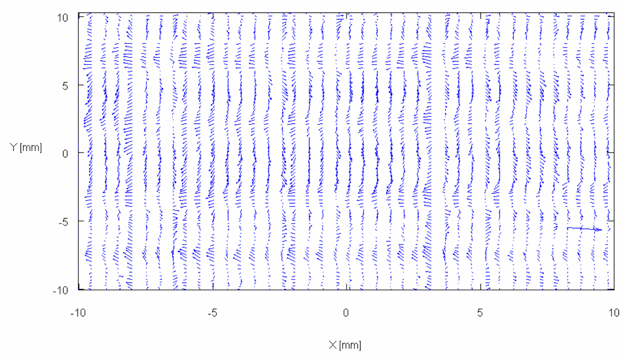

Figure 8: Magnified Q-Class Drop Placement Data

Microphotographs were made of lines printed with the Q-Class printhead in the vertical (parallel to substrate motion) and horizontal (cross printhead) direction. (Figures 9 and 10) The smallest line is one dot or about 62 um wide.

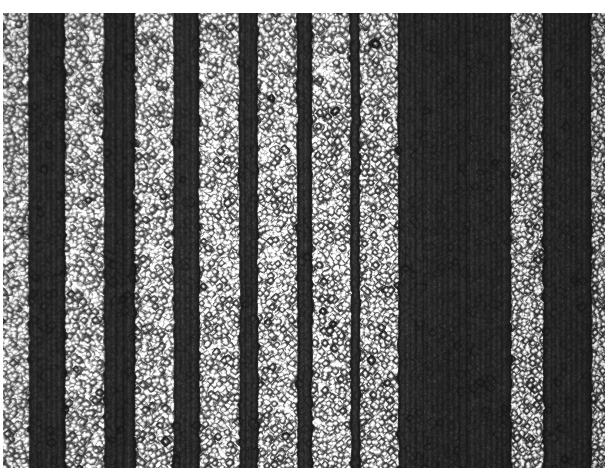

Figure 9: Vertical lines produced with Q-Class

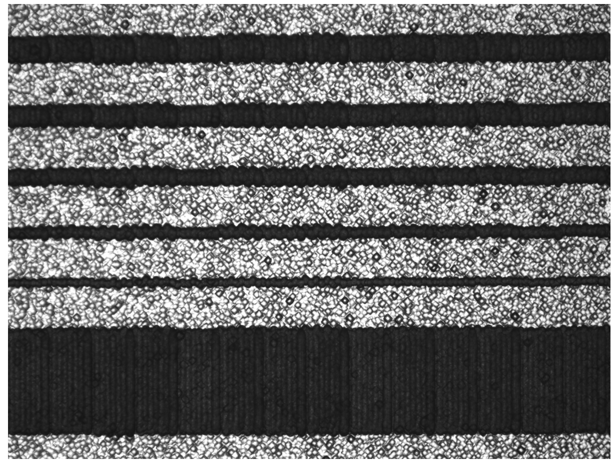

Figure 10: Horizontal lines produced with Q-Class

Challenges

During the development of this application a number of performance anomalies were observed and an understanding of their cause was developed. Discussion of a few of the more interesting ones follows.

Printhead Bow

When the data from the Q-Class printhead was first analyzed an unexpected non-random dot placement error across the printhead was measured. (Figure 11) The nozzle positions were measured and were found to lie on a straight line. In discussion with Dimatix it was determined that this is a known characteristic of Q-Class printheads which they call bow and is caused by drop ejection variation. The amount of bow varies and is specified with each printhead shipped. Printheads with up to 10 um of specified bow have been received. Since each PZT element (128 nozzles) is fired with a single firing wave form, adjusting the fire timing of individual nozzles to correct this error is not possible. While it is possible to reduce this error by applying a force to the side of the printhead it is not a practice that is recommended by Dimatix. In many more traditional printing applications the magnitude of error from this source would be below the required threshold. This anomaly was not observed with Galaxy printheads.

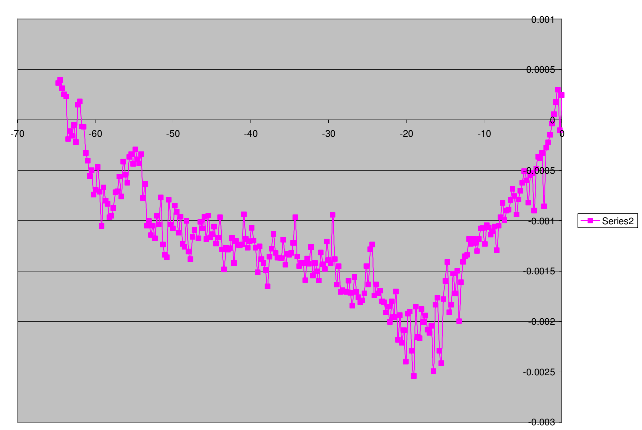

Figure 11: Q-Class Printhead Bow

Thermal Variation

At one point in the development multi-pass print samples were created that showed position errors from print pass to print pass. (Figure 12). At first, dot fire timing was thought to be the cause and the electronics were carefully examined with no errors being found. During the process of replacing printheads the coupling between the heaters, the thermistors and the printheads was disrupted and the printheads were oscillating in temperature approximately +/- 5 degrees C from the desired set point. While the exact cause of the trajectory variation has not been determined thermal expansion of mechanical components and viscosity variations in the fluid are all implicated. Since thermal variation has a much lower rate of change than nozzle firing rates this only showed up in multi-pass print samples. In Figure X it appears that the error only occurs in one diagonal direction. In reality it occurs in both but is not as evident to the human eye in one diagonal as it is in the other. This error was eliminated by improving the temperature control of the printheads.

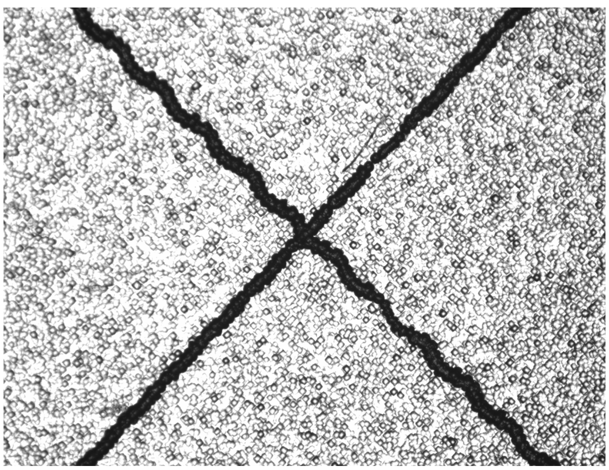

Figure 12: Errors caused by printhead temperature variation

Cleanliness

Printheads have extremely small fluid cavities and pathways and cleanliness is extremely important. Erratic nozzle behavior was noted and in many cases found to be related to debris that crept into the system during assembly. It is also important to perform materials compatibility tests at the system's operating temperature with all parts of the system and fluids that will be used. A small amount of epoxy that was not compatible with the fluid was overlooked in initial testing. It was positioned in the fluid delivery system down stream from the final filter. During operation the epoxy degraded and created particles that were carried by the fluid into the printheads and caused a number of erratic print anomalies as the particles moved around. These problems were reduced by changing components and though implementation of clean environments for assembly of critical system components.

Discussion

The Q-Class printhead was shown to have improved performance over the Galaxy printhead but not to the magnitude that the specifications would indicate. The much smaller size, Versadrop print capability and the lower cost of the Q-Class printhead provide significant advantage over the Galaxy in many applications but the printhead bow of the Q-Class printhead should be carefully considered in applications where high drop placement precision is required.

References

[1] Marlene McDonald, Q-Class – Hybrid Piezoelectric Printheads Combine Carbon and Silicon MEMS for Speed and Enhanced Image Quality, FUJIFILM Dimatix Inc. Lebanon, NH/USA, pg 1.

Acknowledgements

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Author Biography

Mr. Buskirk received a BSEE from the University of Colorado in 1977. He spent 20 years at Hewlett-Packard where he worked on calculators, inkjet printers and managed programs on the Deskjet print cartridges. In 1997 Mr. Buskirk left Hewlett-Packard to form ImTech, Inc., a firm that specializes in developing inkjet equipment fluids and technologies for industrial printing and fabrication applications.