High Precision Jetting and Dispensing Applications Using A Piezoelectric Micropump

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Abstract

Piezoelectric ink jet offers a promising combination of productivity, reliability and uniformity that are appropriate for deposition of precise amounts of material in manufacturing environments. As a micropump, the printhead can place drops very accurately onto a substrate, with placement errors of less than +/- 10 microns. The Spectra SX-128 printhead contains a robust material set, which allows for precision dispensing in a wide variety of applications. For example, flat panel displays (FPD) can be manufactured by using the Spectra SX-128 printhead to ink jet the organic electronic materials, including both large molecule polymers (LEP) and PEDOT. These materials are normally deposited using spin coating, which is a high cost, low yield process. Another benefit of the SX-128 is the ability to calibrate individual nozzles to meet stringent uniformity requirements for display manufacture. By controlling the output of each channel individually, drop sizes are equalized and uniformity requirements for display manufacture can be achieved. The process of measuring very small drops and calibrating the 128 jet printhead to achieve +/- 2% uniformity will be described further in this paper.

Introduction

Ink jet printers can be used for dispensing fluids in a wide variety of applications. Traditionally, ink jet printing is used to replicate an array of pixels on a substrate with precise amounts of colored ink. Digital printing has expanded this capability by including other materials and substrates, for applications such as screen masking, fabric printing, and manufacture of flat panel displays (FPD).

Normal jetting tolerances for ink jet printing can be very demanding. Digital high speed web presses have been demonstrated, printing at 100 feet per minute with 600 dpi native jet resolution. This application has challenging requirements for jet straightness, as well as drop volume and velocity errors. Variations in these outputs will cause undesirable image artifacts. Display manufacture has required yet more precise specifications for drop straightness and uniformity. A new printhead design will satisfy this application. It has impressive drop placement accuracy. The drop-to-drop uniformity requirements are solved by enabling control of individual jet channels. Each of the 128 nozzles can be adjusted by altering the drive voltage and waveform to compensate for small variations in output across the 128 channels.

Printhead Design

The SX-128 printhead is part of the S-Class series of jetting assemblies from Spectra. While other S-Class printheads are designed for graphic arts applications, the SX-128 has the capability to perform as a micropump for precision dispensing applications, such as display manufacture.

The structure of the SX-128 printhead is formed from resin filled carbon material. The 128 jets are driven by two slabs of PZT material each with 64 channels. The pumping chambers are created with stainless steel laminates. The precision nozzle plate is formed in nickel and then gold plated for protection from aggressive chemistries. All of these materials are extensively tested with the fluids required for flat panel display manufacture, which include light emitting polymers in organic solvents and acidic Pedot hole injection layer.

The additional unique feature of SX-128 is the 128 channel flex connector, shown in Figure 1.

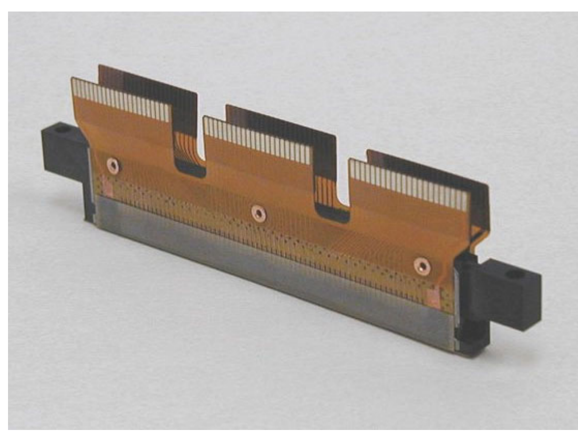

Figure 1. SX-128 printhead with per nozzle driver.

This connection strategy allows direct control of the drive pulse of individual channels. With this approach, variations in individual nozzles can be compensated by adjusting the drive pulse amplitude or form. Slow, small, fast or large drops can be trimmed to achieve the average nozzle performance. Uniformity of drop volume or drop velocity can be adjusted by the user. The capability to adjust all nozzles to +/-2% uniformity will be demonstrated below.

In order to satisfy the production requirements for display applications with a robust print engine that can be produced with high yield, a series of printhead design changes were investigated. The first challenge was to reduce the size of the drops generated by the ink jet. Modifications to existing 30 pl jet designs were shown to produce 10-12 pl drops with good jetting characteristics. A robust new material set was used in the printhead design to provide compatibility with light emitting fluids. Nozzle straightness specifications were improved by a factor of three. However, drop volume variability caused by part or process variations is about +/-10%. In order to meet drop volume uniformity requirements for flat panel display manufacture, each channel in the 128 jet printhead can be individually calibrated.

Characteristic Properties

Each drop generated by the firing of the piezoelectric channel has repeatable output for billions of cycles. Important drop characteristics include drop straightness, drop mass and drop velocity. Drop mass and drop velocity are typically linear with drive voltage. Figure 2 shows the relationship between mass and velocity, as a function of increased drive voltage. With high molecular weight polymers, it is likely that the best drop formations are found with lower drop velocities.

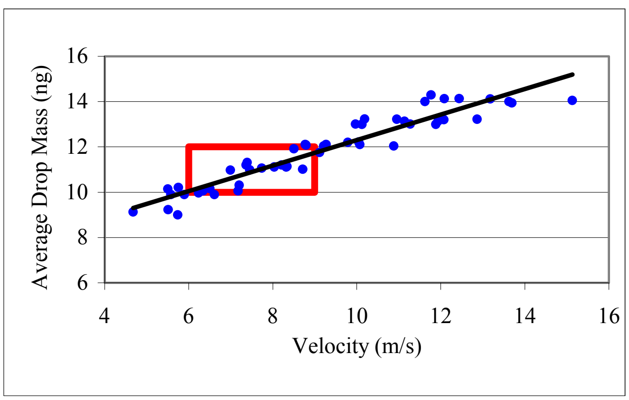

Figure 2. Linear relationship of drop mass and drop velocity.

Frequency Response

Operating speed of the FPD manufacturing line will determine the optimal DOD print frequency. Many prototype systems require firing frequencies of only 1 to 2 kHz, with production goals of 5 kHz or higher. The SX-128 printhead is designed to provide uniform performance over a wide frequency range. The chart in Figure 3 shows drop velocity as a function of operating frequency. The hollow line shows frequency response for a single jet. The filled line gives the frequency response for the same jet, while all 128 other jets are firing simultaneously. The lines are nearly coincidental. These results suggest that the printhead output will be consistent, regardless of changing print cycles. However, jetting properties of the polymer fluids will also have a strong influence on the maximum operating frequency.

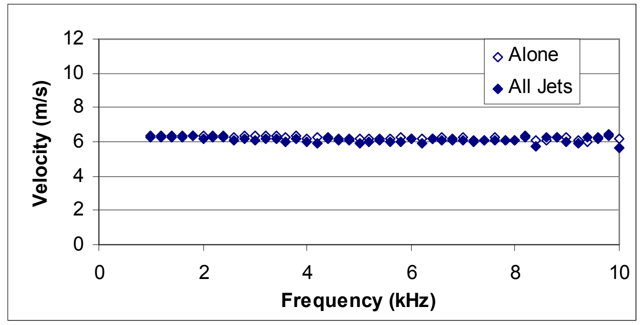

Figure 3. Frequency response of jet velocity.

Ink Jet Materials

The specialty materials used for FPD manufacture provide another challenge for ink jet technology. The Pedot deposition process requires that robust materials be used in the ink jet system. Due to the aggressive properties of Pedot, a new material set was required for the SX-128 printhead. Extensive materials compatibility testing was required to qualify the optimal material set. This testing included soak tests of material coupons and printhead subassemblies, as well as extended jetting tests using typical LEP and Pedot materials. A number of inert materials or protective coatings are used in the construction of SX-128. This will enable the printhead to be used in a variety of new applications.

Drop Placement

There are two components that determine the drop location accuracy. The first is jet straightness and the second is the location of the jet with respect to the substrate. Improvements in drop straightness are critical to enabling the success of this application. A new nozzle design was required to provide improved straightness as compared to commercially available printheads. Additionally, it became clear that X and Y straightness were equally important in this application. A measurement scheme was implemented to measure nozzle errors in both directions.

The second component of drop placement is the accuracy with which the nozzle is positioned relative to the substrate. Machine and staging errors will contribute to placement error. The flatness of the precision substrate allows for small standoff distances, which can lessen the impact of trajectory errors.

In Figure 4, per nozzle straightness of the SX-128 jet printhead with the new nozzle design is shown. In this example, drop placement error from all sources is less than +/- 5 microns at a 1 millimeter standoff. The specification for this printhead is shown at +/- 10 microns.

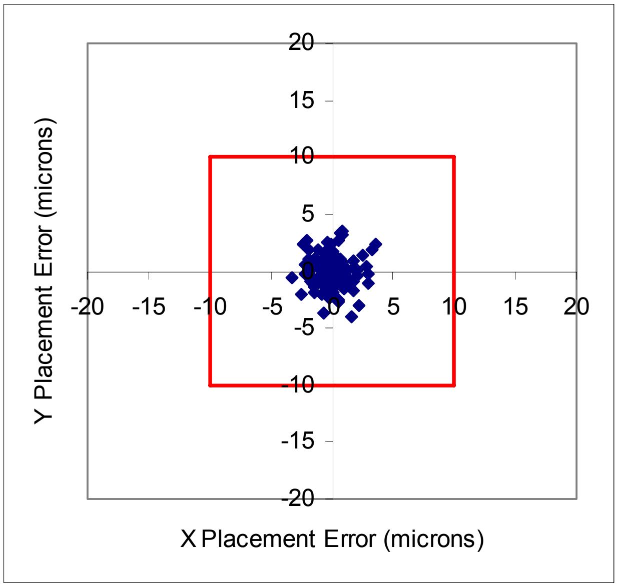

Figure 4. Drop placement errors at 1 mm standoff.

Drop Formation

Drop formation is the combined result of jet dynamics and fluid properties. Because LEP materials have high molecular weights, their jetting characteristic tends to result in long ligaments[1] and erratic firing behavior. The combination of ink jet design and fluid formulation can be used together to optimize the firing behavior.[2] Many LEP fluids are specially formulated for ink jet printing. Viscosity, surface tension and shear rate are important properties for the fluid. Firing conditions such as pulse amplitude, pulse width and pulse frequency will also affect drop formation.

Jet Calibration

The SX-128 printhead provides direct connection to each of the jet channels. This means that each of the nozzles can be calibrated individually. This allows the user to improve drop uniformity and eliminate that error contribution. The printhead must first be tested to determine the initial condition. Drop volume and drop velocity are interdependent outputs, which cannot be individually adjusted. It is necessary to decide which parameter should be controlled to +/-2%. Adjustment of one parameter does not guarantee compliance of the second parameter.

Calibration Process

In the first example, we consider the case where the printhead is tuned to achieve uniform velocity across 128 channels. The data shown in Figure 5A is the velocity of each jet before the calibration process. These jets were measured at a single drive voltage, and all jets are performing within +/- 0.5 m/s of the head average. Voltage offsets are used to adjust to the desired average condition. Jets which ran slow use more voltage, jets which ran fast use less voltage. The adjusted data is shown in Figure 5B. Now all jets are running at +/-0.1 m/s. The resulting drop volumes are shown in Figure 5C.

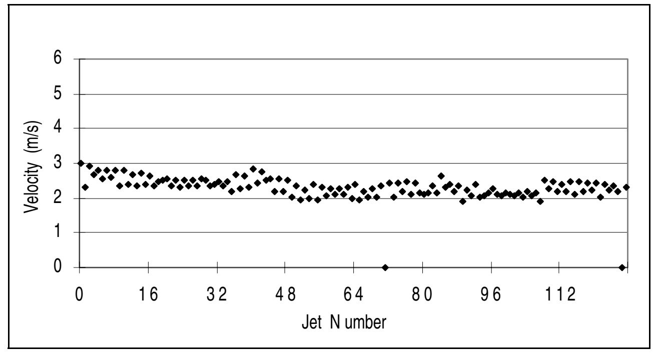

Figure 5A. Drop velocity vs jet number for untrimmed head.

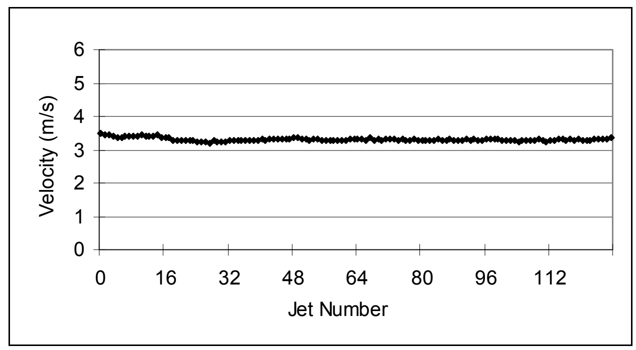

Figure 5B. Drop velocity vs jet number after trimming.

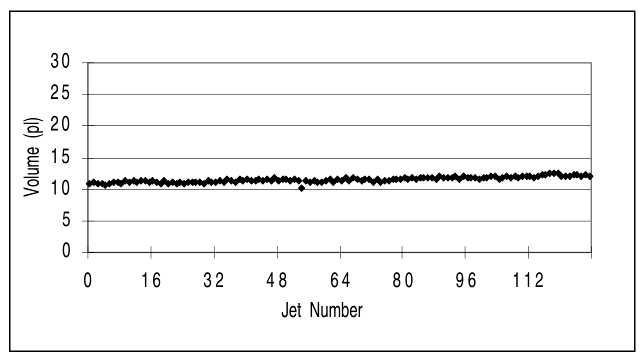

Figure 5C. Drop volume vs jet number after trimming.

Often, it is the drop volume which is the critical output. With such small drops, it is challenging to attain precise measurements of drop volume from individual nozzles. Drop must be optically evaluated or individually weighed. The precision of this measurement must be negligible when compared to the 2% adjustment target. Figure 6 is an image captured from the optical measurement system that is used to calibrate the printhead for drop volume.

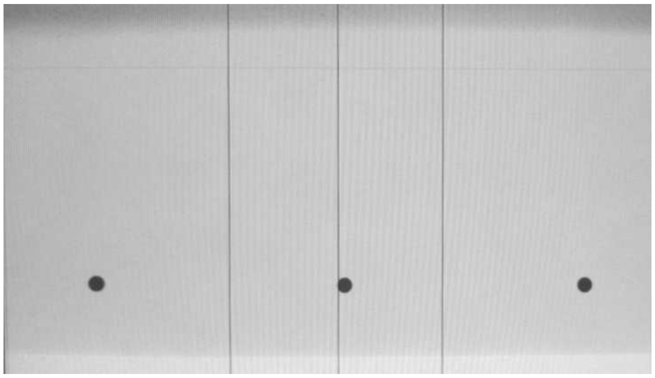

Figure 6. Image of three drops taken at 0.5mm standoff.

After the initial measurement, a volume/voltage characteristic curve, shown in Figure 7, is used to predict the voltage offset for each of the nozzles. The driver electronics are reprogrammed with 128 new voltages and the measurement process is repeated. At this point, most of the nozzles have achieved the target variation and only a few must be adjusted a second time.

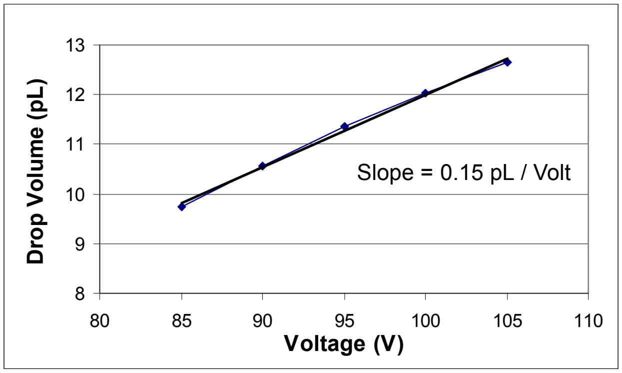

Figure 7. Drop volume vs drive voltage for SX-128 printhead.

In Figure 8A, results from the drop volume measurements are shown for one SX-128 printhead. The average drop volume is 12pL. Variation across the channels is approximately +/- 10%. Next, the volume/voltage curve is used to predict the new voltage setting for each jet. Jets are remeasured and individual fliers are manually tweaked. After calibration results are shown in Figure 8B. All jets are now performing within 2% of the average drop volume.

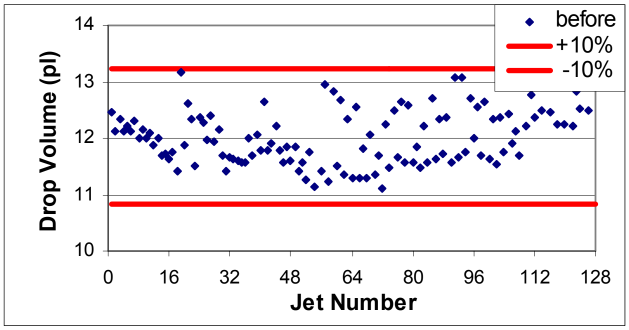

Figure 8A. Drop volume for individual jets before jet trimming.

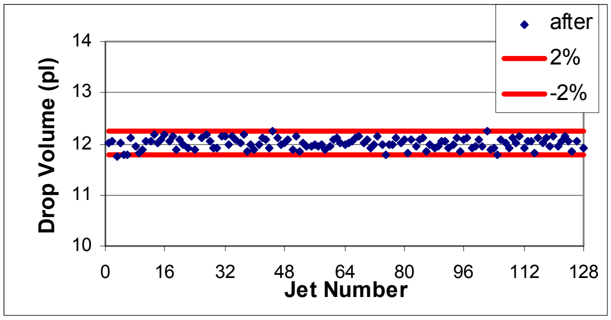

Figure 8B. Drop volume for individual jets after jet trimming.

Conclusion

For ink jet printing of display materials to be a practical manufacturing process, the ink jet printhead must meet exacting specifications for drop straightness, drop volume uniformity, and reliability. The SX-128 printhead has been engineered to meet these specifications. Improvements in drop location accuracy allow for precise deposition of fluids. Jet calibration on a per nozzle basis allows for unprecedented control of drop uniformity. Each of these improvements enable high precision dispensing using a piezo micropump.

References

1. E.I. Haskal *et al.*, SID Digest 2002, p 776, (2002)
2. L.T. Creagh *et al.,* IDMC 2003, Taiwan, (2003)

Biography

Marlene McDonald received her BA 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 Spectra, Inc. in Hanover, NH. She has focused on computational modeling, jet design, and new product development.