Performance Improvements for Commercial Piezo Printhead

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Abstract

There are many technical challenges to developing and manufacturing a piezo-based printhead for industrial applications. Velocity uniformity has an impact on image quality. Velocity uniformity refers to the variation of drop velocity from jet to jet across an individual printhead. Drop placement in the process direction impacts by drop velocity variation, which results in time-of-flight errors. Previous Spectra presentations have reviewed, in detail, the mechanisms of crosstalk. Crosstalk is the measure of the mechanical, fluidic and electrical interactions between components within a printhead and results in drop mass and velocity variation. Often, crosstalk is most notable between neighboring jets. Variations in drop mass and velocity can have a negative impact on image quality. Excessive crosstalk can even lead to jet decay and outage. The frequency response of a printhead is also an important parameter and must be understood. Printhead average drop velocity and mass will often change as a function of the operating frequency. In addition, crosstalk is not usually constant throughout the operating frequency range for any given printhead design.

This paper presents data of frequency response, velocity uniformity, and crosstalk. Spectra has developed technology to improve printhead performance relative to crosstalk, frequency response, and velocity uniformity. Results from testing of piezo based printheads manufactured for use in the case coding market will be discussed to demonstrate the performance enhancements and the impact on image quality.

Introduction

Digital printing systems have been in use in the case coding market for many years. Digital systems are used to print continuously variable data such as item numbers, use-by dates, and manufacturer's bar codes directly onto the secondary carton. Bar codes pose a significant challenge because the codes must be legible by a bar code scanner, which requires very good image quality. Often large numbers of jets fire simultaneously to get a large enough bar code for scanning. Customers often print logos and other information that must be legible by a person from a reasonable distance. Other challenges include printhead standoff. Printheads must be capable of spitting drops over a large distance, compared to other industries such as wide format printing, where the distance to the substrate is tightly controlled.

Suppliers of these print systems are under constant pressure to increase the operating speed and size of printheads used in this application. Spectra manufactures a 256 addressable channel printhead with two nozzles per jet to meet this market need. This printhead is based on Spectra's Commercial Carbon Printhead (CCP) technology, and jets hot melt ink, which solidifies on contact with the substrate. However, market pressure has driven the development of a printhead that can operate consistently at higher line speeds in the same application. This will be accomplished by applying Spectra's Flex Link, Inverted PZT (FLIP) technology now used in the NOVA product. The new printhead is called Galaxy. Crosstalk is much reduced with the new design throughout the operating range which will enable higher line speeds while printing reliable images.

Printhead Design

There are common design features between the CCP and FLIP Galaxy printheads. In each case, a flexible circuit is used to provide the electrical pulses to the PZT. An electrode pattern is sputtered onto the PZT. The pattern is designed to cause the shear mode activation of the PZT when the correct voltage pulses are applied. The PZT and other components are epoxy bonded to a carbon plate that is used as the jet module body. The jet module body has a common ink-refill chamber running along the spine of the body that supplies all jets with ink. One PZT is bonded to each side of the jet module to form two sets of 64 pressure chambers. Two jet modules are assembled to a nozzle plate assembly with screws and other custom hardware. The nozzle plate assembly's design and function is nearly identical in the two designs. There are two nozzles for each pressure chamber. The nozzle spacing on a CCP head is .0055 inches versus .005 inches on a Galaxy printhead. Each head is designed to eject drops between 140 and 145 pl per jet activation. All jets can be fired simultaneously.

The primary difference between CCP and Galaxy printheads is in the jet module body. The pressure chamber geometry of a CCP module is machined into the surface of the jet body. The PZT is bonded directly to the jet module body and forms the outer wall of the pressure chambers. The PZT extends above the pressure chambers to form the outer wall of the refill chamber as well. The flex circuit is soldered directly to the electrode pattern on the outside surface of the PZT to provide the electrical pulses. An electrode pattern is on both sides of the PZT. The CCP printhead has been in production for three years.

The jet modules in a Galaxy printhead are more complex. The pumping chamber features are made from two metal plates, and one sheet of plastic. Sheets of metal are bonded to the module body. This is the inner wall of the pressure chambers. The plate adds stiffness to the assembly. Sixty-four pressure chambers are machined into a second set of plates that are bonded to the stiffener plates. The plastic sheets, referred to as flex links, form the outermost walls of the pressure chambers, and the ink refill chamber along the spine of the module. The PZT is directly bonded to the flex links with the electrode pattern facing toward the pressure chamber. The PZT is only tall enough to cover the pressure chambers. The voltage pulse is transmitted to the PZT from the flex circuit through a circuit on the flex link. Both the CCP and Galaxy configurations can be used to make different size modules, to achieve optimal drop mass and velocity uniformity, for different drop size requirements.[3]

Spectra's NOVA product uses modules of similar configuration to the Galaxy printhead. The NOVA printhead is primarily used in wide format printing applications and has been in production for a year and a half.

Performance Comparison

Velocity Uniformity

Velocity uniformity is important to image quality. For a barcode to be readable, it is important that each bar have a clear leading and trailing edge. Drop velocity variation between neighboring jets will result in the drops reaching a substrate at different times. This phenomenon is referred to as time-of-flight error, and results in jagged edges. Drop placement in the process direction is impacted by drop velocity variation, which results in time-of-flight errors.

A plot of normalized drop velocity from a typical CCP printhead is shown in figure 1. The velocity of each drop was measured independently at an operating frequency of 7 kHz. The drop velocity was normalized using the head average drop velocity of the Galaxy printhead tested below. There are a total of four PZTs in a CCP and Galaxy printhead. PZT 2 and 4 are on the first module, and PZT 1 and 3 are on the second. The velocity is very uniform for each PZT, and the variation from PZT to PZT is very small.

A plot of normalized drop velocity from a typical Galaxy printhead is shown in figure 2. The velocity of each drop was measured independently at an operating frequency of 8 kHz. There is some variation between jets on the same PZT and some variation in the average drop velocity between PZTs. The Galaxy printhead has not been introduced to production and it is expected that velocity uniformity will equal the CCP printhead above. The drop velocity uniformity is expected to match that of the NOVA printheads, designed using FLIP technology, now in full production.

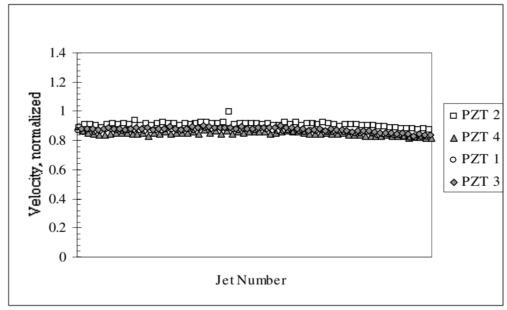

Figure 1. Velocity plot of CCP printhead, 7 kHz operating frequency, normalized by head average velocity of Galaxy printhead.

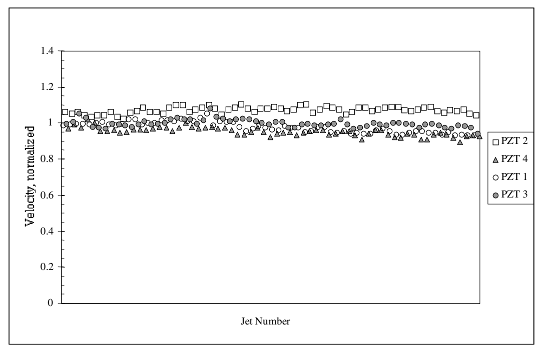

Figure 2. Velocity plot of Galaxy printhead, 8 kHz operating frequency, normalized to head average velocity

The velocity of the Galaxy printhead is 10% higher, which will reduce the magnitude of time of flight errors at higher line speeds.

Crosstalk

Crosstalk is a result of the interaction between neighboring jets. Crosstalk can be quantified in the laboratory by measuring the drop volume and velocity of individual jets while neighboring jets are activated. Contributors to crosstalk can be mechanical, electrical, thermal or fluidic.[1] Contributions from each of these effects are additive and cause drop velocity and volume to change as a function of the number of jets being fired and the proximity of those jets to one another. Increasing the number of active jets often increases the absolute magnitude of the crosstalk. Excessive crosstalk can even lead to jet decay and outage. Positive crosstalk is observed when drop volume and velocity of the observed jet increases. Negative crosstalk is observed when drop volume and velocity decrease as additional jets are activated.

The operating frequency of a printhead changes the magnitude of crosstalk. The jet module design used in CCP and FLIP printheads is based on Spectra's shear mode piezoelectric technology.[2] A jet module is activated by applying an electric field to the PZT. Parasitic extension modes of the PZT may excite harmonic modes of the entire structure. The impact can be a change in drop volume and velocity with changes in operating frequency, dependent upon the natural frequencies of the structure.

Figures 3 and 4 show crosstalk of a CCP and a Galaxy printhead, respectively. Crosstalk was determined by measuring the velocity of each jet individually and then each jet with all jets on. The CCP head was run at 7 kHz, which corresponds to the acceptance test criteria used in production to qualify CCP heads for shipment. The crosstalk of the CCP printhead is positive and between 5% and 23%. There is significant variation between modules. The magnitude of the crosstalk of the CCP head is large and positive. Positive crosstalk results in larger drops and higher jet velocity. This can lead to jet instability and death.

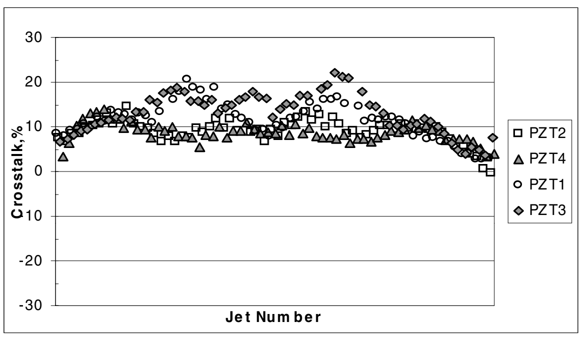

Figure 3. Crosstalk of CCP printhead, measured at 7 kHz, percent deviation from initial jet velocity

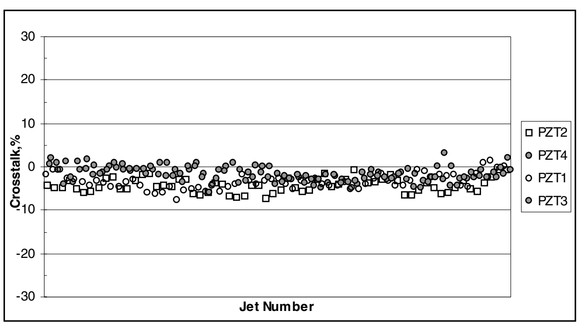

Figure 4. Crosstalk of Galaxy printhead, measured at 8 kHz, percent deviation from initial jet velocity

The Galaxy head was run at 8 kHz to measure crosstalk. This frequency corresponds to the first large peak in the frequency response of this head configuration. The data is shown in figure 4. The crosstalk is between positive 3% and negative 8% at this condition. Negative crosstalk means that as more jets are activated, jet velocity and drop mass of individual jets is reduced. This eliminates the problem of over activating jets, as more jets are turned on. There is very little variation between jet modules and corresponding PZTs.

Frequency Response

Figure 5 shows the frequency response with crosstalk of the CCP printhead. The bottom curve is the jet velocity of an individual jet in the middle of the printhead. The top curve is the velocity of the same jet, but with all jets firing. The velocity is normalized using the jet velocity of the Galaxy printhead at 8kHz.

The crosstalk of this jet is 23% at 7 kHz. The crosstalk varies from 4 to 11.5 kHz. At 11.5 kHz, the observed jet became weak and died. The crosstalk is very large and positive over most of the frequency range, with a very large peak of 43% at 8.7 kHz.

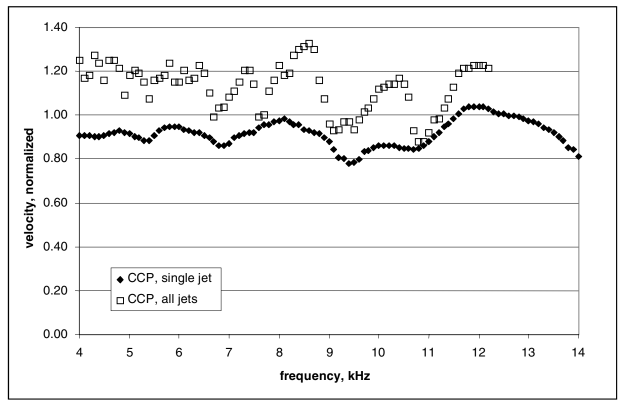

Figure 5. Frequency response with crosstalk of CCP printhead.

Figure 6 shows the frequency response with crosstalk of the Galaxy printhead. The data is normalized using the jet velocity at 8 kHz. The velocity of the Galaxy head is fairly uniform over the frequency range. The crosstalk is much reduced and also negative. At the worst condition, 7 kHz, the crosstalk is -13%; at the peaks, 8 and 12 kHz, the crosstalk is nearly zero. Nowhere along the frequency response curve is the crosstalk for this individual jet positive. This indicates that jet death due to over excitation is significantly reduced.

Printed Images

Images were printed with each printhead. The standoff was controlled at .187 inches to simulate the standoff expected on a production line. The paper speed was controlled to achieve 600 dpi resolution in the process direction. The photographs below show only a portion of the printed image for better illustration. Each image was collected after the printhead was operated for three minutes. Two images printed with the CCP head are shown to illustrate the impact of over exciting jets.

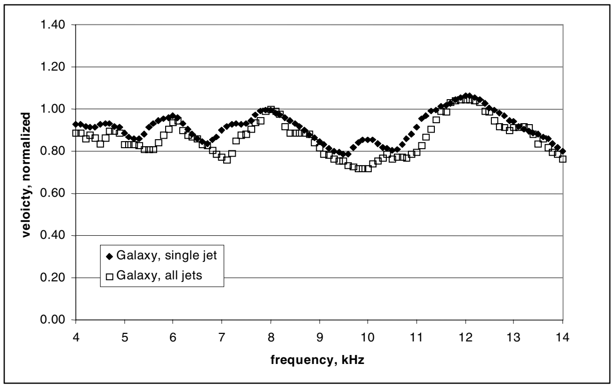

Figure 6. Frequency response of Galaxy printhead.

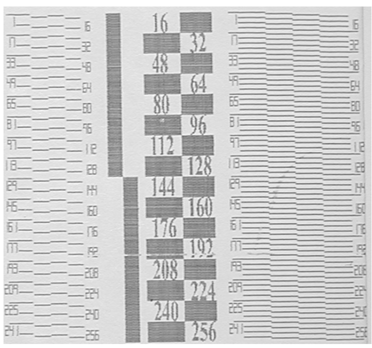

Figure 7. CCP test image, 11 kHz

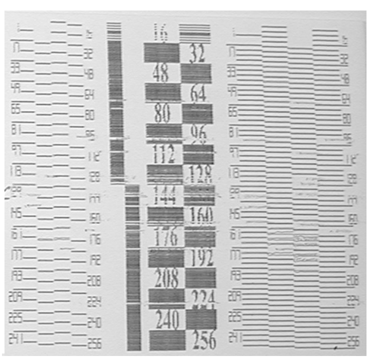

Figure 8. CCP test image, 12 kHz

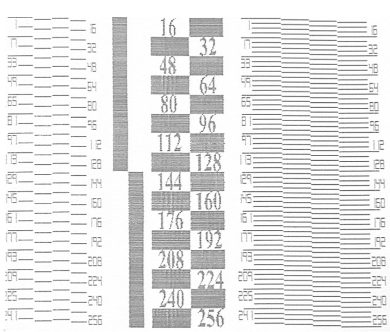

Figure 9. Galaxy test image, 14 kHz

In figure 7, one jet has grown weak. At 11 kHz the drop velocity of this head is at .88 and the crosstalk is nearly zero.

Figure 8 shows an image collected at 12 kHz. At 12 kHz, the drop velocity indicated in figure 5 is 1.04 with crosstalk of 19%. Significant jet death has occurred after three minutes of jetting. This printhead would also operate very poorly at frequencies near 8.6 kHz and 10.4 kHz, the crosstalk peaks in the frequency response curve.

Figure 9 shows an image printed with the Galaxy printhead. This image shows no signs of weak jets. This printhead was shown to operate from “0” to 14 kHz without decrease in performance.

Conclusion

The performance of the modules used in the Galaxy printhead is superior to that of the modules used in the CCP printhead. By making the module stiffer, and reconfiguring the electrode patterns to a single layer on the PZT, crosstalk is significantly reduced throughout the frequency range up to 14 kHz. Uniform crosstalk throughout the operating window results in predictable operation anywhere in this range. This enables the operator to run the case coding system at higher line speeds while maintaining acceptable image quality.

Acknowledgements

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References

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Biography

Thomas G. Duby is a Development Engineer of Spectra, a leading developer and manufacturer of piezoelectric ink jet printheads, related consumables and accessories. Duby joined the company in 1997. He helped to bring to market the CCP case-coding printhead and has led several project teams bringing new products to market, including the NOVA printhead. Duby holds a BS in mechanical engineering and an MS in mechanical engineering from the University of Massachusetts, Amherst. Contact author’s e-mail address: tduby@spectra-inc.com.