Crosstalk Study of a High Speed Shear Mode Piezo Ink Jet Printhead

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Abstract

The phenomenon of crosstalk is well known in the ink jet printing industry. The shared mechanical components and interconnected fluid channels of an ink jet printhead may cause jet crosstalk between adjacent channels. Crosstalk is well known for its negative impact on image quality because it causes drop velocity and volume variations. Excessive crosstalk may even lead to jet deaths. Crosstalk can vary significantly with different operating parameters, jetting frequencies, and printhead designs. To meet the image quality and reliability requirements of a high speed printhead for industrial printing applications, it is necessary to understand the nature of crosstalk problems. A printhead design should be optimized to minimize the crosstalk effects on its performance.

This paper presents an analysis of crosstalk of ink jet printheads and the potential effects of crosstalk on image quality. It categorizes modes of crosstalk that arise out of fundamentally distinct physical phenomena, and describes how these effects conform to the principle of superposition. Included are coupled field finite element analyses which confirm potential sources of crosstalk. The results of these studies show how an understanding on the root causes of crosstalk can lead to improved printhead designs.

Introduction

Digital printing has become a requirement in many new industries, driving ink jet technology to offer more jets, higher speeds and greater duty cycles. But, as the number of addressable jets increases, the interactions between them can increase as well -- a phenomenon known as crosstalk. Crosstalk can adversely affect the volume and velocity of the jets. In order to meet image quality requirements, crosstalk must be minimized whether there are two or two hundred jets firing.

The outputs used to measure crosstalk include the volume and velocity of the individual drops. These metrics are measurable in the lab and provide a good indicator as to the quality of the ensuing print in a user application. Finite element modeling is one of the tools used by Spectra to study the effects of crosstalk. These models have demonstrated which parameters are useful in eliminating crosstalk and suggested some opportunities to enhance ink jet designs.

What is Crosstalk?

Crosstalk is a result of the interaction of neighboring jets. The operation of one jet in an array of jets will affect the volume or velocity of its neighboring jets, which can result in a deterioration of image quality. Positive crosstalk occurs when the firing of additional jets increases the volume and velocity of the observed jet. Negative crosstalk occurs when the volume and velocity of the observed jet is reduced by the firing of its neighbors. The effects of crosstalk can be seen in some imaging applications, causing drop size variations and drop placement errors.

Contributors to crosstalk include structural, thermal, fluidic, and electrical interactions between neighboring jets, or banks of jets. These mechanisms are present in nearly all modes of drop-on-demand ink jets. In thermal ink jet, the flash heating of an ink channel can affect the ink temperature, which then influences the size of neighboring drops. Undampened fluid resonances often limit jetting frequencies with water based inks. Electrical crosstalk can arise due to resistive voltage drops in shared conductors. Piezo driven ink jets can experience crosstalk due to the mechanical deformation of the driver. For example, with extension mode piezoelectric ink jet, the PZT driver is often sliced into individual actuators in order to achieve mechanical isolation. System level approaches include a limit on the firing of neighboring channels in a printhead.

The effects of crosstalk are generally additive, so firing more jets can lead to greater crosstalk. The various mechanisms for crosstalk are additive as well. Because mechanical, fluidic, and electrical crosstalk mechanisms all coexist in the same structure, these mechanisms can combine to create a complex system. In order to understand the response of this system, it is necessary to apply the principles of superposition to the problem of crosstalk.

Mechanisms for Crosstalk

Mechanical Deformation

In the jetting structure diagrammed in Figure 1, each jet shares side walls with two neighbors. As the PZT deforms in shear mode, the side walls are also subject to deformation, as shown in Figure 2, greatly exaggerated. This deformation can result in the stretch, compression, or bend of the side wall, depending on the material characteristics involved. The deformation of the neighboring channel causes a pressure change, which results in crosstalk between the channels.

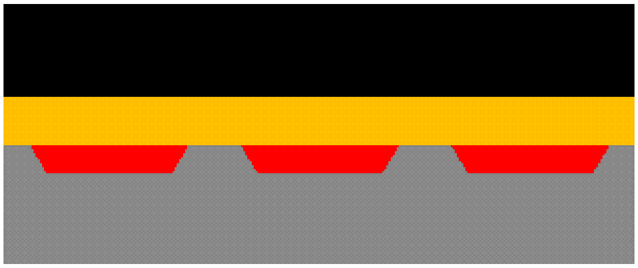

Figure 1. Shear mode jet, cross-section

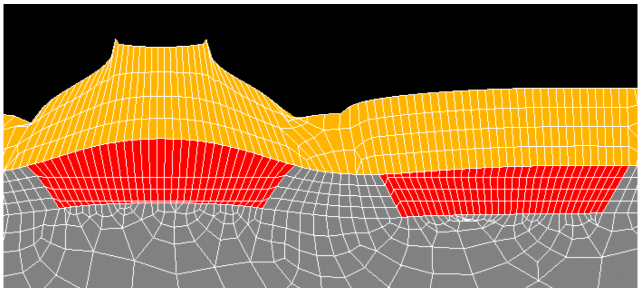

Figure 2. Deformed jet, cross-section

Crosstalk between jets causes fluctuations in the velocity or volume of the ejected drops. These changes in volume and velocity are the measurable indicators of the presence of crosstalk. By firing jets in a variety of combinations, the effects of crosstalk are more easily isolated. For example, the effect of mechanical crosstalk on the jets can be shown by measuring the velocity of the center jet with each of its neighbors firing. Figure 3 shows how the velocity of the center jet is changed when each of its neighbors are fired. The closest neighbors have the greatest influence, and the effect diminishes further away from the jet. The effect shown in Figure 3 is ‘positive crosstalk’, because the firing of neighboring jets increases the velocity of the observed jet.

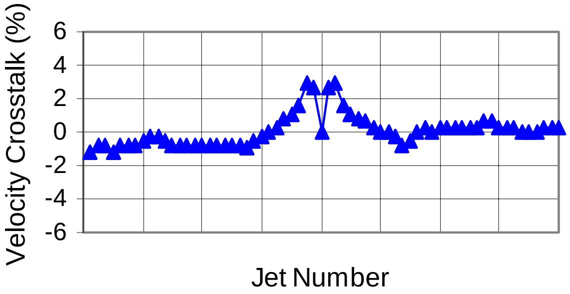

Figure 3. Positive mechanical crosstalk

Alternatively, the data generated in Figure 4 is the result of negative crosstalk. Firing of the neighbors has the effect of reducing the volume and velocity of the center jet. The optimal structure will balance these effects.

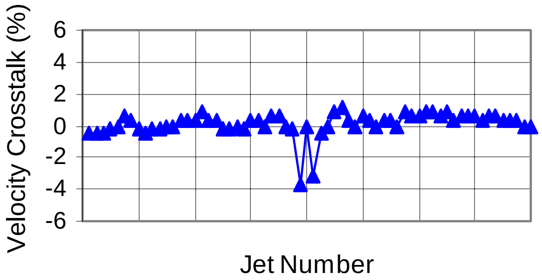

Figure 4. Negative mechanical crosstalk

Structural Harmonics

Shear mode jets use the D15 property of the PZT to deform the walls of the pumping chamber, as shown in Figure 5. In this convention, 1 represents the axis along which the electric field is applied. The descriptor 5 represents the resultant rotation around the 2-axis.

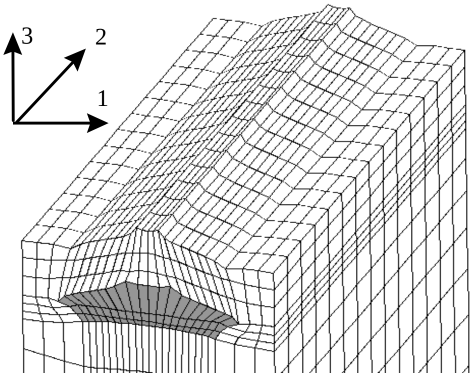

Figure 5. Piezoelectric D15 deformation

Figure 6. Multi-jet structure, harmonic deformation

However, the transformation of electrical energy to mechanical motion is not always perfect. The dominant E field in 1-direction causes the shear, but the existence of E field in 3 direction leads to PZT contraction/extension in 1 and 2 directions. The D31 deformation can result in extension along the length of the pumping chamber. This extension causes deformation in the jetting structure and may excite harmonic modes. A deformed structure in Figure 6 illustrates the effect of harmonic resonance. These modes are dependent on frequency.

Fluid Reflections

An additional contributor to crosstalk can be the fluid refill chamber. A drop-on-demand jet creates an acoustic wave which travels both directions through the pumping chamber. Because the refill is not infinitely large, some acoustic energy is lost at the entrance. These reflections will have spatial and harmonic dependencies. Increasing the damping or compliance of the refill chamber can reduce the magnitude of the reflected waves. Figure 7 shows the how the perturbation of a single jet firing can be transmitted through the fluid refill to the center jet. The jet measured is not mechanically coupled to its neighboring jets.

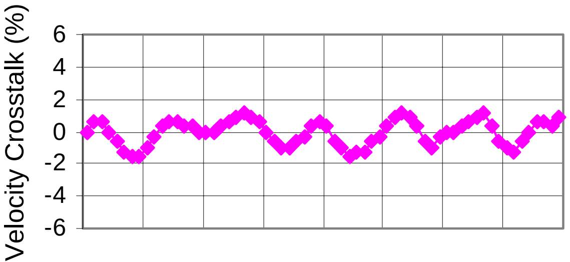

Figure 7. Fluid wave in the refill chamber

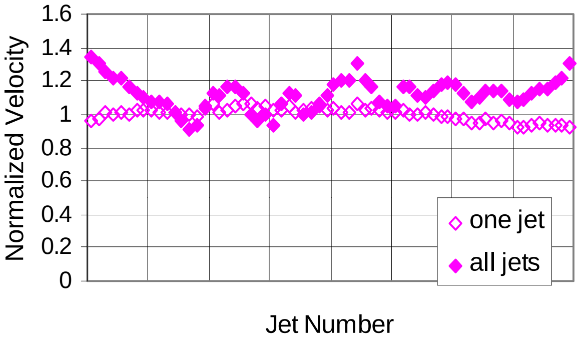

Figure 8. Crosstalk effect with all jets firing

Superposition

The effects of crosstalk appear to adhere to the principles of superposition. A negative effect and a positive effect can add together to yield zero. Two negative effects become a greater negative. The small positive contributions from each neighbor can add together to be one large positive effect.

Figure 8 shows how the velocity of a jet firing alone changes when it is fired along with all the other jets in the array. The velocity variations seen in Figure 8 are the result of crosstalk between the jets in the array. The resulting crosstalk as shown in Figure 8 is not the result of a single effect but rather the summation of several effects, superimposed to show a complex relationship.

By using superposition to account for the effect of fluid reflections, mechanical vibrations, and electrical effects, we can reduce this data to its constituents. Then we can hope to understand the root causes of crosstalk.

Investigation Results

Electrode Pattern

Finite element modeling has given us great insight to the effects of the PZT electrode pattern. The width of the electrode and ground patterns have a strong effect on the performance of the jet. Substantial effort has been undertaken to optimize these patterns in the existing products. The results of these efforts have increased the efficiency of the jetting structure, while decreasing crosstalk among the jets. The PZT deformation is more localized, D15 is eliminated, and the effect on the neighboring channels is diminished. The result is lower drive voltages and decreased crosstalk.

Wall Stiffness

The stiffness of the walls of the pumping chambers has a direct effect on the nature of the mechanical crosstalk described above. If they are machined from a material with a lower modulus than PZT, then the walls are susceptible to deformation by the deflection of the PZT. By using other high modulus materials to form the pumping chamber walls, the material strengths can be balanced. The finite element model has been useful in illustrating how material choice and wall geometry can affect jet crosstalk.

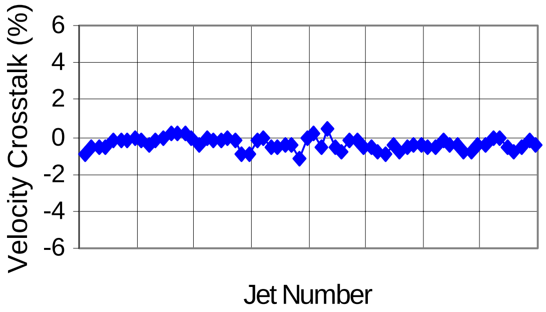

Figure 9. Mechanical crosstalk

The above design elements can be combined to improve jetting performance. The result is a decrease in the mechanical deformation, eliminating the effect of parasitic D31, and increased efficiency of the jetting structure. These improvements give higher efficiency and less crosstalk.

Figure 9 shows the effect that every jet on an array has on the middle jet. Contributing effects from the neighbor jets are less than 1/2%.

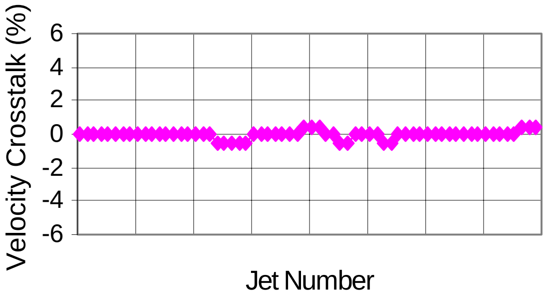

Figure 10. Fluid wave in the refill chamber

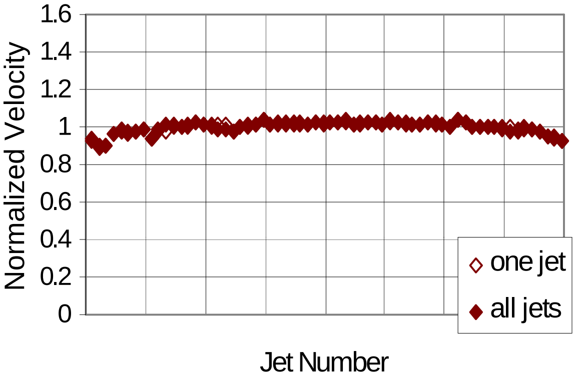

Figure 11. Crosstalk effect with all jets firing

Fluid Damping

Damping of the acoustic wave can be achieved in several ways. Viscous losses can reduce fluid perturbations, as can acoustically tuned flow passages. Impedance matching of the jet to the nozzle has an important effect as well. Refill compliance has two major components: the modulus of the jetting fluid and the compliance of the refill structure. Compliance of the wall of the refill area is proportional to wall area and inversely proportional to thickness and Young’s modulus. Thus compliance can be increased by increasing the size of the refill passage, by choosing a material with lower modulus, or by using thinner walls. We are able to increase this component of compliance by several orders of magnitude. This tuning of the fluid and the structure allows the printhead to operate with more jets, at higher frequencies, and with less interaction.

Figure 11 shows velocity of each jet firing by itself and with all of its neighbors. Total crosstalk with all jets firing is 2%.

Conclusion

An effort was made to understand and improve the mechanisms for crosstalk in Spectra shear mode ink jets. The root cause analysis and the principle of superposition is used to explain combined phenomena. Finite element modeling and a fundamental understanding of these issues can be used to improve the design of drop-on-demand printheads. An understanding of the root causes for crosstalk results in the ability to produce printheads with less jet interactions, lower drive voltages and higher operating frequencies. These printheads can better meet today’s demanding digital printing applications.

Biography

Marlene McDonald received her BA from Dartmouth College and her MS from the University of Massachusetts Amherst. She has worked as a development engineer at Spectra since 1994, focusing on jet design and product development. Yong Zhou has a Ph.D. from Thayer School of Engineering at Dartmouth College. His interests include high efficiency piezo transducers, acoustics, fluid-structural interactions and design optimizations.