Manifold Ringing Mitigation Through Tuned, Lumped Compliance

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Abstract

Ringing, or acoustic pressure oscillation, in the ink feed manifold system of a piezoelectric printhead can cause significant drop velocity and mass variation. These pressure induced velocity and mass changes cause visual print quality artifacts. One critical test condition is the end of a solid fill region where all the jets of a given color were running and stop suddenly. The manifold system reacts to the sudden stoppage in exiting ink flow, resulting in a rise and subsequent oscillation in pressure. If a drop is then fired at the time coinciding with the minimum or maximum pressure, the drop's position (due to velocity change) may be significantly altered relative to nominal. This effect can be observed in light dithers following a solid fill.

Analytical modeling and experimental verification were used to design a mitigation scheme for manifold ringing using passive, tuned, lumped compliance. The location was chosen for maximum global pressure amplitude mitigation; the amount of compliance was limited by manufacturing capability; and the entrance to the added compliance was chosen to tune the resonator at the dominant manifold acoustic resonance.

Introduction

Print quality artifacts can be caused by many sources in piezoelectric printheads. One possible source is the excitation of acoustic resonances within the manifold fluid system that feeds ink to the individual drop ejecting jets. As the number of jets fed by the manifold system and the firing frequency increase, the burden placed on the ink feed system to deliver a constant flow of ink both spacially and temporally is increased. Thus, while print quality artifacts caused by excitation of manifold acoustic resonances (ringing) may not be observed in many customer related, low coverage prints, certain printing situations may result in substantial changes in drop velocity and mass.

One such case is shown in Figure 1, where a solid fill is interrupted by a white space. In this case, the manifold load changes from 100% to 0% load and back again. In the figure, the printing direction is from bottom to top and the change in intensity (due to velocity and drop mass variation) is evident as the manifold system reacts to the sudden change in mass flow being drawn from it and rings, i.e. oscillates at its natural frequencies.

Another ringing example is shown in Figure 2. This represents a more customer like print, a bar chart. In this case a large number of the black jets are turned on and back off to make the bar outline, and then the ringing is observed in the surrounding light black dither background. Clearly, this manifold design requires modification to mitigate the ringing induced print quality artifacts.

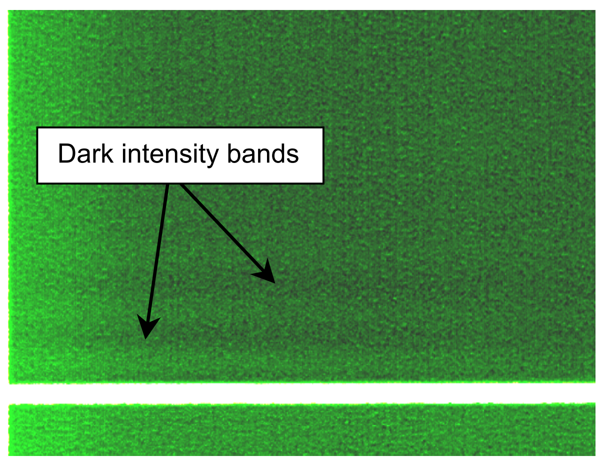

Figure 1. Sample of solid fill manifold ringing

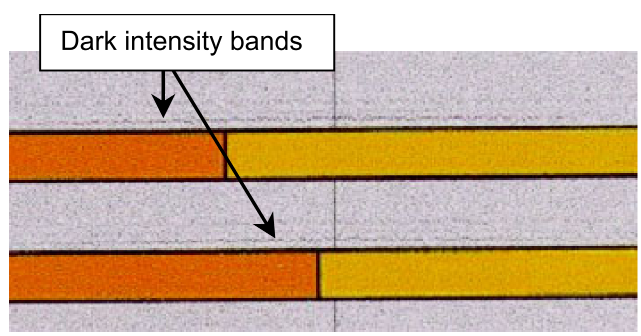

Figure 2. Sample of low dither manifold ringing

Problem Definition

A measurement system for manifold ringing was developed based on intensity variation. The intensity of manifold ringing for a solid fill case (equivalent to Figure 1) is shown in Figure 3. Both the high frequency variation more easily observed in the low dither case (Figure 2) and the low frequency variation observable in the solid fill case are clearly evident in the intensity measurement. It is clear that both of these resonant frequencies must be attenuated to obtain good print quality.

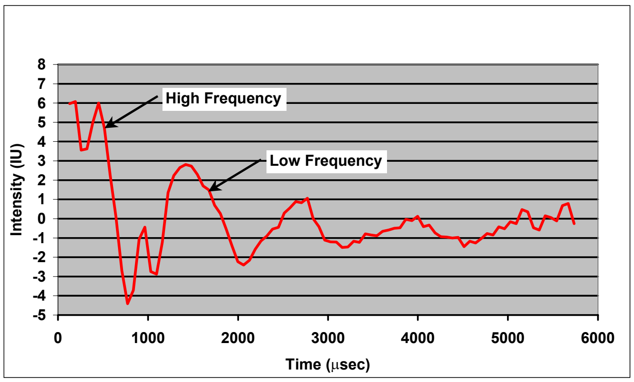

Figure 3. Measured manifold ringing intensity variation

In addition to experimental verification, analytical modeling was completed to predict the manifold system response to sudden changes in exiting mass flow (flow into jets for drop ejection). The model, described in more detail in references 1 and 2, uses finite difference methods to solve the manifold fluidics, with coupled fluid-structure interaction and single jet lumped parameter models, and gave good qualitative prediction of the ringing observed experimentally. I.e. the frequencies were predicted well, but the actual pressure amplitudes in the printhead manifolds were not measured for correlation. The model was then used to perform geometry sensitivity studies to determine which attributes of the geometry would provide the most leverage to mitigate the ringing pressure amplitude. Compliance in the primary manifold volume was found to dominate, with certain requirements of distribution through the system. Also, with additional considerations, the design could be tuned to focus on the manifold resonant frequencies and gain additional pressure amplitude mitigation.

Results

Using the analytical modeling results as a guide, prototype printheads were built with various amounts of added compliance and frequency tuning characteristics to determine what was required for good print quality. Manufacturing variation was then considered to establish the nominal new manifold design goal. The measured solid fill intensity compared to the original baseline design is shown in Figure 4.

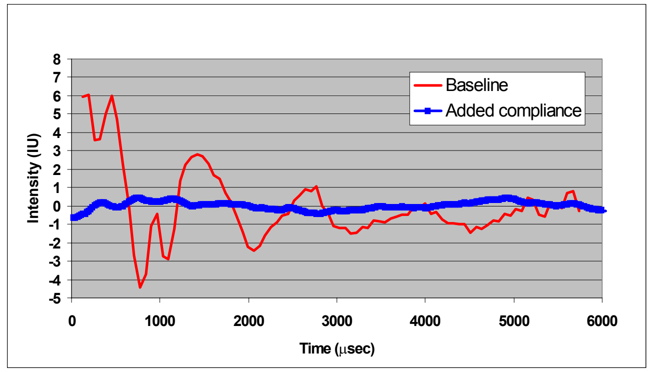

Figure 4. Mitigated manifold ringing

Once a concept prototype was built and tested to verify the model, the problem of manifold ringing induced print quality artifacts was reduced to a design and manufacturing problem. A specific amount and distribution of compliance was required in all four manifolds (cyan, magenta, yellow and black), but manufacturability requirements limited the design flexibility. A schematic of one end of the final design manifold structure with the added compliance features is shown in Figure 5.

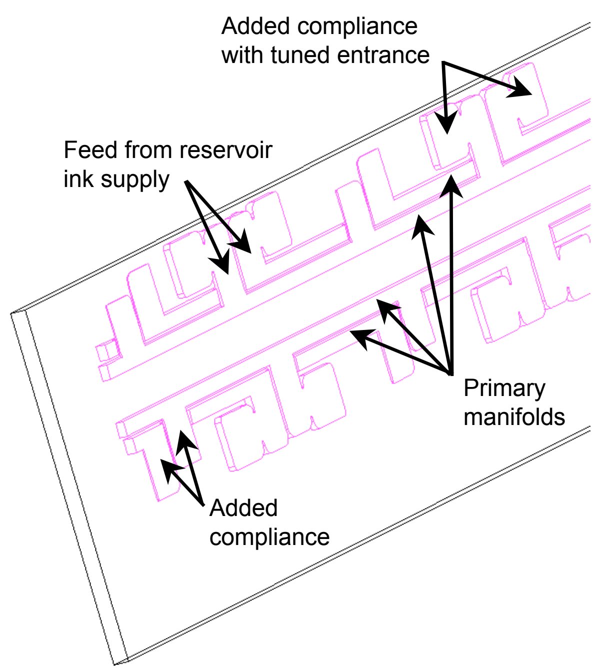

Figure 5. Manifold structure with added compliance

Conclusion

Tuned, lumped compliance was distributed along the manifold structure in a piezoelectric printhead to passively mitigate acoustic pressure oscillations causing print quality artifacts. The pressure oscillations (ringing) caused drop velocity and mass variations in both solid fill and low dither prints resulting in unacceptable intensity and dot placement variations. The addition of tuned, discrete compliance reduced the ringing to virtually unobservable levels.

References

1. Burr, Ronald F., Tence, David A., and Berger, Sharon S., "Overview of Phase Change Piezoelectric Ink Jet Fluids Modeling and Design", FED-Vol. 239, Proceedings of the ASME, 545-552.
2. Berger, Sharon S., Burr, Ronald F., Padgett, James D., and Tence, David A., "Ink Manifold Design of Phase Change Piezoelectric Ink Jets", IS&T's NIP 13: 1997 International Conference on Digital Printing Technologies, pp 703-708.

Biography

John M. Brookfield received his B.S. degree in Aeronautics and Astronautics from the University of Washington in 1991 and S.M./Ph.D. degrees in Fluid Mechanics from Massachusetts Institute of Technology in 1993/1998. Since 2000 he has worked in the Solid Ink, Printhead Research and Development group at Xerox Corporation's Office Group in Wilsonville, OR. His work has primarily focused on fluid mechanic analysis, design and optimization for the Phaser family of printers and advanced technology printheads.