Ink Volume Displacement In An Impulse Printhead With Bilaminar Transducer

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Introduction

The Tektronix Phaser III color printer was introduced in 1991. This color printer is based on a proprietary printing technology known as phase change ink jet. The printhead uses inks that are solid at room temperature, but operates at an elevated temperature at which the ink is liquid. Ink droplets are ejected on demand from an array of piezoelectric ink jets onto the paper. Because the droplets solidify quickly, most of the color remains on the paper surface rather than wick through the paper fibers. These qualities allow phase change ink jet printers to produce bright colors and high print quality on a wide variety of printing media (e.g., paper weights and finishes).

Impulse phase change ink jets compress ink in a pressure chamber, generating a pressure differential which induces a flow of ink out of the jet interior (pressure chamber) through a nozzle. A controlled droplet of ink is ejected from the nozzle and deposited on the printing media.

In the Phaser III color printer, a piezoelectric driver mechanism is used to deflect one pressure chamber wall and compress the ink. This driver mechanism consists of a piezoelectric material bonded to a thin metal diaphragm, forming a bilaminar plate. When a voltage is applied to the piezoelectric material, it expands and contracts, causing the bilaminar plate to bend and compress the ink in the pressure chamber. The volume displacement of such an ink jet driver mechanism directly influences the velocity and volume of the ejected ink droplets. Volume displacement efficiency and uniformity are, therefore, critical requirements for a multiple nozzles ink jet array such as that used in the Phaser III.

This paper investigates the operation of the Phaser III printhead piezoelectric driver mechanism using laser interferometer deflection measurements and finite element method (FEM) calculations. Effects of various design and operating parameters such as misalignment and temperature on the efficiency of the Phaser III printhead are considered. These results are used to optimize volume displacement and uniformity in future phase change ink jet printhead designs.

Phaser III Printhead and Experimental Device Descriptions

Figure 1 shows a printing unit from a Tektronix Phaser III color printer, including the ink jet array printhead, flex circuit and ink reservoir and melt box. The printhead is designed to print phase change inks at an operating temperature of approximately 140°C. An array of 48 nozzles on one side prints black. On the other side, a second array of 48 nozzles is divided into three subgroups of 16. Each of the three subgroups prints one of the subtractive primary colors.

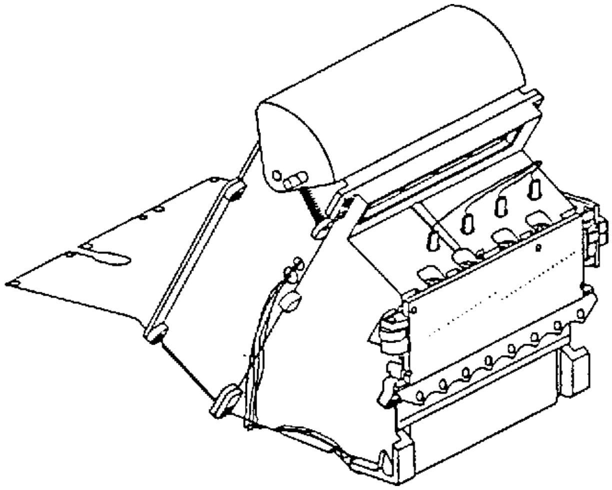

Figure 1. Printing Unit of Tektronix PHASER III Color Printer

The printhead consists of a brazed stack of photochemically machined 316L stainless steel plates, to which 96 lead zirconate titanate (PZT-5A) driver elements have been epoxy bonded. A flex cable on the back of the printhead contains a heater and electrical interconnects to provide electrical drive signals to each of the 96 driver elements.

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Figure 2 is a cross-section of one ink jet device in the 96 nozzle array. The driver elements are cut into hexagons from slabs of 0.010 inch thick PZT. The center-to-center spacing of the hexagons matches that of the 3 mm diameter pressure chambers contained within the printhead stack. These hexagon PZT elements are bonded to a 0.004 inch stainless steel diaphragm layer which covers the pressure chambers. The PZT hexagon/ diaphragm layer combination forms an array of bilaminar electromechanical transducers which are used to eject the ink droplets on demand.

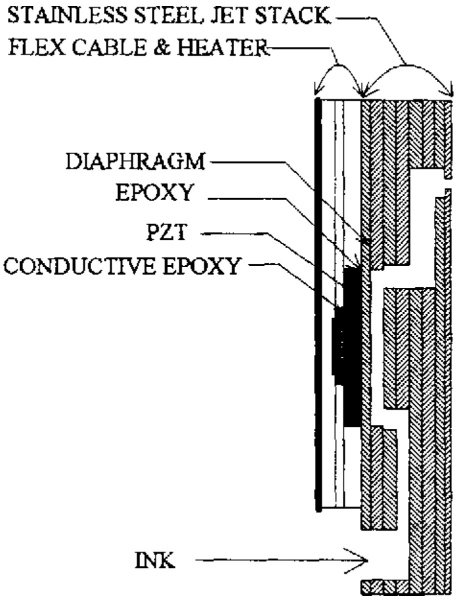

Figure 2. Print Head Design

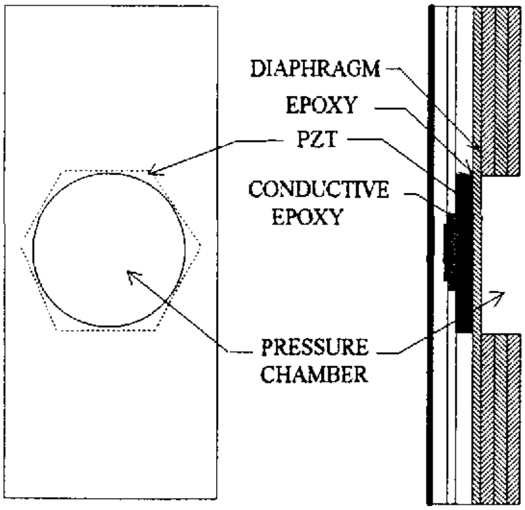

Figure 3. Experimental Print Head Device

Figure 2 also illustrates the flex circuit which is laminated onto the surfaces of PZTs and the back of the stainless steel jet stack. The electrical contacts between copper conductors in flex cable and the PZT element electrodes are formed by 0.005 inch thick silver loaded epoxy.

Figure 3 shows the fundamental construction of the experimental device used in this study. It is identical to the back portion Phaser III printhead described above (i.e., an array of 96 PZT/diaphragm bilaminar plate drivers and a flex cable with heater). The front portion of the stainless steel printhead stack was modified so that a beam from the laser interferometer can scan across the entire pressure chamber to measure the mechanical deflection of stainless steel diaphragm when a periodic voltage signal is applied to the PZT hexagon.

Laser Interferometer Description

Measurement of small displacement using the laser interferometer has been described in the literature (References 1 and 2). A schematic drawing of a laser inter ferometer is given in Figure 4. The incident beam from an He-Ne laser (λ = 6328 Å) is split into two half-power beams by a cube beamsplitter. After reflecting from the sample surface and the reference mirror, the probe and the reference beams are recombined by the same beamsplitter and form an interference pattern at the detection point. The interference light intensity, I, at a detection point is described by the following equation:

$$I = I_p + I_r + 2\,(I_p\,I_r)^{1/2}\cos(4\pi\Delta d/\lambda)$$

The light intensities, I_p and I_r refer to the probe and the reference beams, respectively. The optical path-length difference between the two beams (Δd) results in a change in the interference light intensity, which can be detected by several different methods depending on the magnitude of the displacement change (Δd). In measuring a displacement smaller than 300 Å, a dc feedback loop is used to stabilized the system against thermal and mechanical optical path-length fluctuation. The displacement measurements from all of the experimental ink jet devices reported in this paper where generated by a sinusoidal electrical drive signal of 20 Vpp.

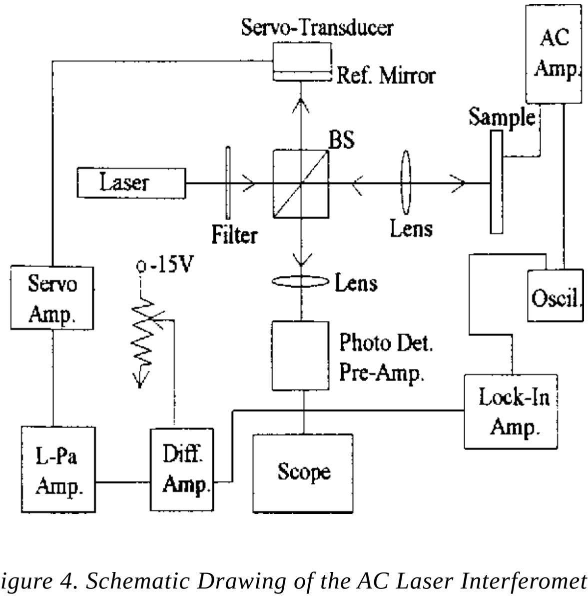

Figure 4. Schematic Drawing of the AC Laser Interferometer

Results and Discussions

In the sections below, baseline displacement measurements and the effect of various parameters on the displacement are examined.

Baseline Displacement Measurements

Figure 5 shows the driver deflection (Å/V) as a function of radial position across the 3 mm diameter pressure chamber at room temperature. The measurements were taken at room temperature with drive signal frequencies of 1 and 10 kHz. As expected, the displacements at 1 and 10 kHz are similar since the natural resonance frequency of the PZT/diaphragm bilaminar plate is calculated by FEM to be much higher either of these frequencies (approximately 163 kHz). The measured deflection is 3.0 Å/v at the center.

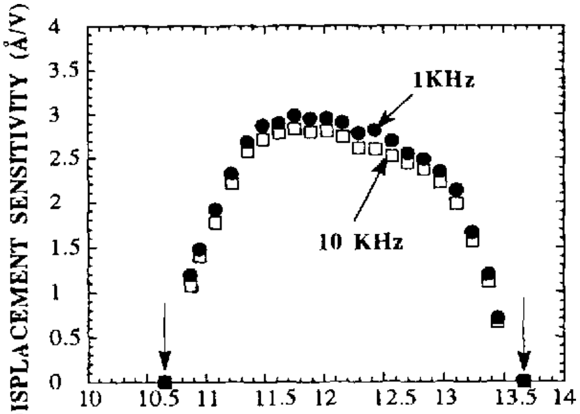

Figure 5. Displacement sensitivity as a function of position across the pressure chamber at the drive frequency 1 and 10 KHz.

A FEM analysis of the bilaminar driver has also been performed. The FEM predicted center deflection is considerably higher at 13.8 Å/V. In the FEM analysis, the PZT/diaphragm bilaminar plate considered to be axisymmetric (circular) and clamped on the outer radius. The epoxy layer joining the PZT and the metal diaphragm is assumed to be 4 μm thick. The FEM analysis does not, however, include the effect of the flex cable and heater. The cause of the discrepancy between the measured and FEM deflections at room temperature is discussed further in the following paragraphs.

Temperature and Flex Cable Backing

Figure 6 shows the deflection as a function of temperature. It is observed that at 140°C the deflection is at its maximum at the center of the bilaminar plate and its value is recorded up to 11.3 Å/V. The displacement profile and its amplitude suggest that at 140°C the bilaminar plate works mostly in the bending mode. In fact, the results from the double beam laser interferometer measurements of the both surfaces of the bilaminar plate have confirmed indeed at 140°C the device operates mostly in the bending action (i.e., both sides of the driver are displaced similarly).

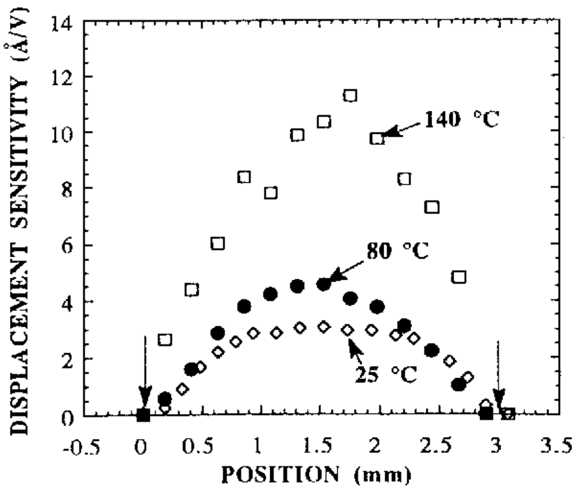

Figure 6. Displacement sensitivity as a function of Temperature

Figure 7 plots the volume displacement (mm^2 Å/V) calculated from the measured deflection profiles at 25, 80 and 140°C. At low temperature, the flex cable backing is stiff and constrains the motion of the bilaminar plate. This constraint reduces the volume displacement efficiency of the device. At 140°C, however, the backing materials in the flex cable become soft and the bilaminar driver can displace a volume of up to 36 mm^2 Å/V. For a typical drive signal of 100 Vpp as in Phaser III color printer, the bilaminar plate of an ink jet can displace a volume of about 360 pL in its pressure chamber.

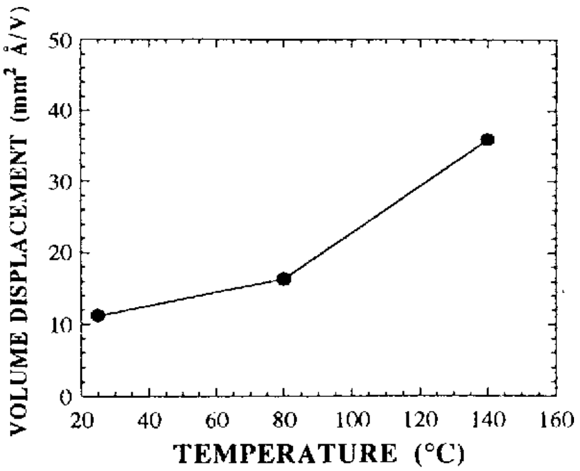

Figure 7. Volume displacement as a function of temperature

To further examine the effect of the flex cable backing, Figure 8 shows driver deflection profiles at 25°C and 140°C without the attached flex cable backing. The volume displacements are calculated to be 36.0 mm^2 Å/V and 43.6 mm^2 Å/V at 25°C and 140°C, respectively. The results of these measurements indicate the effect of the flex cable backing on the performance of the printhead at low temperature. At 140°C, the effect is much less pronounced.

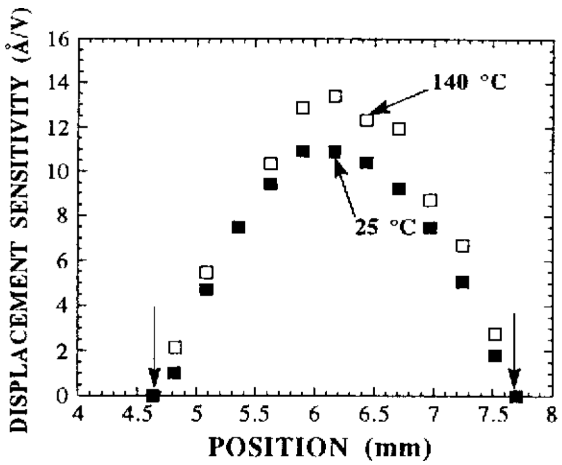

Figure 8. Displacement sensitivity as a function of temperature without an attached flex cable and heater backing

PZT and Pressure Chamber Alignment

Figure 9 shows deflection profiles scan vertically across two bilaminar plates, one with PZT and pressure chamber alignment within 0.002 inch and the other with 0.016 inch of misalignment in the same direction of the scan. The overall displacement amplitudes are low since the data were collected at room temperature. However, the detrimental effect of the PZT-to-pressure chamber misalignment is clearly shown.

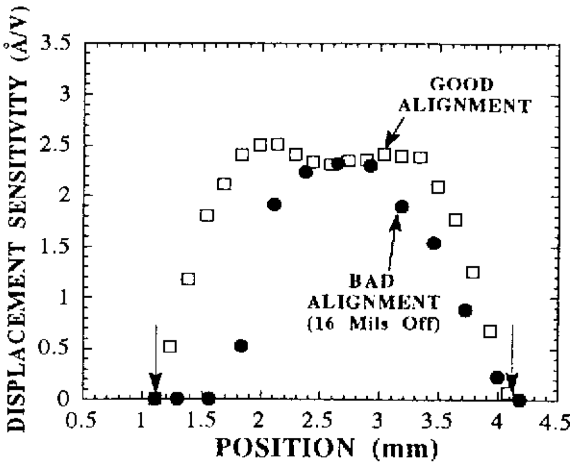

Figure 9. Displacement sensitivity as a function of PZT and the pressure chamber alignment

To further study the misalignment effect, a series of experimental Phaser III printheads with different PZT and pressure chamber alignment errors were fabricated and tested.

The ink droplet velocity performance of one of these experimental printheads is showed in Figure 10. As expected based on the laser interferometer measurements, the ink jet devices with higher alignment error will eject ink drop at lower velocity. Figure 11 shows the ink drop velocity plotted as a function of the PZT and pressure chamber alignment error. A clear correlation between misalignment and driver efficiency is indicated. It is noted that the alignment errors plotted in Figure 10 and 11 were normalized against the allowable specification in Phaser III printhead production.

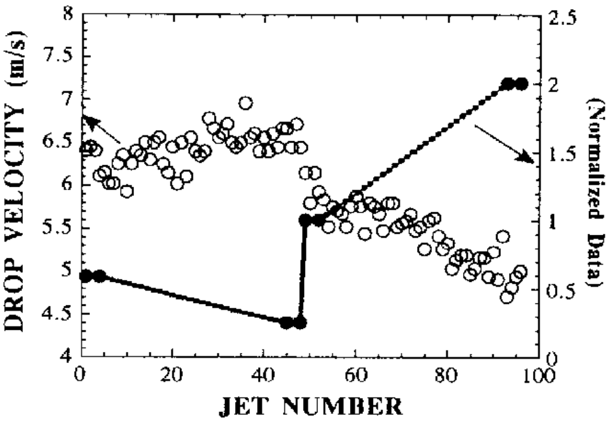

Figure 10. Drop velocities at various alignment errors from across 96 jets array printhead.

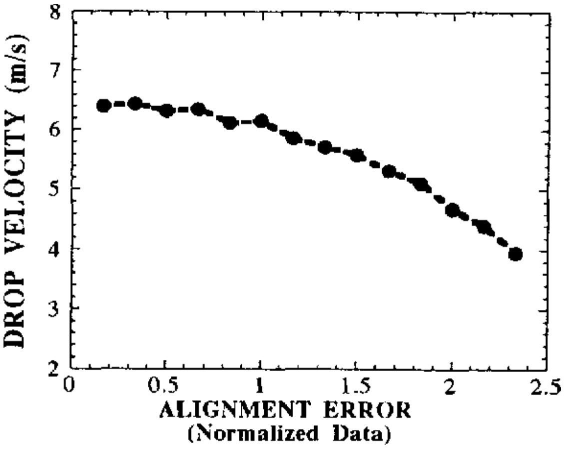

Figure 11. Drop velocity as a function of PZT and pressure chamber alignment error.

Driver Loading

All of the measurements and FEM calculations presented thus far are based on zero load (i.e., ambient pressure). However, in the actual Phaser III phase change ink jet application, the driver compresses and expels phase change ink[3] with a viscosity of about 15 cP in from confined fluid geometry. Under normal jetting conditions, the Phaser III printhead peak pressure chamber load is about 1.5 atm[4]. Figure 12 shows the results from the FEM modeling of load effect on displacement at the center of a PZT/diaphragm bilaminar plate. Volume displacement is predicted to be strongly affected by the driver loading under these conditions.

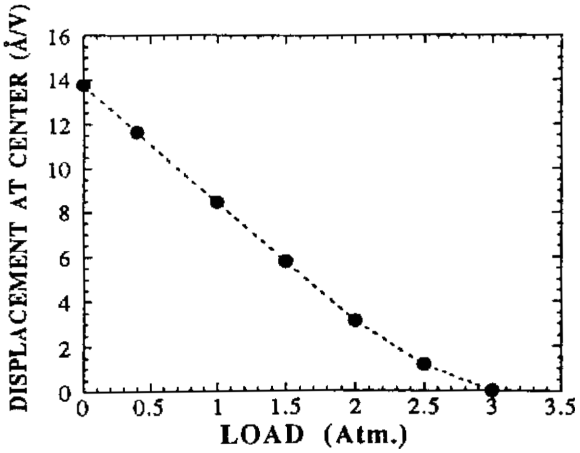

Figure 12. FEM study of load effect on displacement at center of PZT/diaphragm bimorph

Conclusion

From the knowledge of displacement sensitivity and uniformity of PZT/diaphragm bilaminar plates, one can predict their performances in an ink jet printhead without building the entire device. The laser interferometer measurements and the FEM analysis have been proven as useful tools to get an accurate determination on the displacement values from the ink jet's bilaminar driver. In addition, these tools can be extremely useful in the development of the optimized transducers for future printhead designs.

Acknowledgments

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References

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4. United State Patent No. 5,155,498.