

Thermal Inkjet: Meeting the Applications Challenge

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Abstract

Thermal inkjet technology (TIJ) has been the widely preferred method of inkjet printing since its market inception in 1985. TIJ has made rapid progress since that time, to the point where it challenges electrophotography for the print quality of plain paper text and graphics, rivals silver halide for photographic image quality, and enables the highest performance/price ratios in digital printers. Thermal inkjet technology continues to enjoy a greater unit market share for printers that any other digital printing technology and all other inkjet technologies combined. Nevertheless, competing inkjet methods have (re-) emerged, most notable piezoelectric inkjet. In this paper, we will discuss trends and comparisons in the key areas of print (image) quality, print speed, and reliability. Long life heads introduced with the HP 2000C will be discussed which compete very favorably with the so-called "permanent" piezoelectric devices.

Introduction

It is ironic that the users of printing devices do not care what technology is used to deliver the desired output. The manufacturers of these devices have chosen to pursue a particular technology for a variety of reasons and strive to keep their products competitive. The consumer is the winner in this scenario since there is independent development to ensure each technology fills the needs.

Thermal and piezoelectric technologies are prime examples of this technical scenario. Hewlett Packard broke new ground with the introduction of the 2000C by challenging color print speeds of electrophotography at much lower costs. Part of the cost advantage is derived from replaceable ink supplies that are separated from the printhead. This separation brought about a new paradigm in printer architecture for HP inkjet office products. The user will replace a printhead only when the quality is deemed unacceptable. Many improvements in printhead materials and processes were made to ensure long life heads. New printer algorithms were developed as well.

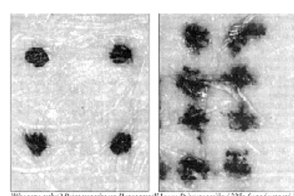
Reduced drop volume and increased nozzle count significantly improved the color quality and speed. Primary contributors for increasing printhead life are improved ink channel designs, thermal control, and printhead servicing with a cleaning fluid. These improvements truly rival piezoelectric designs for consumer printer products.

Print Quality

Most of today's printing is black text, but the demand for better quality color graphics and images is increasing dramatically. Ink colorant selection and delivery method is the key to meeting these demands. TIJ has successfully brought pigment inks to the desktop printing market to rival electrophotography in quality over a wide range of inexpensive papers found around the world. A successful printing experience is enabled by the right choice of inks, print engine and mechanism design, media, firmware, and color management and image processing.

Several manufacturers of desktop printers and large format devices have claimed ink independence with piezo. Evidence indicates that the best text print quality is attained with pigment colorant-based inks, and the only technology that has brought this to the desktop market in the office and home is TIJ. More recently, large format printer manufacturers which produce outdoor signs claim the need for pigment based inks. TIJ manufacturers now have introduced pigment inks for that market as well. With the exception of expensive hot melt wax ink based systems, using TIJ has demonstrated the ability to equal or surpass the quality of piezo printing in each of these important applications.

Figure 1 is a 225X magnification of individual dots on plain paper. Note the lack of colorant wicking into the adjoining paper fibers with the pigment ink.



a b

Figure 1. (a) *TIJ Pigmented ink; (b) Piezo dye ink*

TIJ manufacturers have relied on water based inks for both dye and pigment based systems. Some piezo manufactures in the large format markets promote solvent-based pigments for fast drying times. Typically solvent systems will not produce the sharpness that high quality printing demands because the solvents quickly spread along the surface of the media unless special coatings are applied.

Water based inks do not pose as many health and safety concerns as solvents. Although the thermal process limits the choice of solvent, several have been demonstrated to operate successfully in the lab. TIJ has chosen not to commercialize these for these environmental and safety reasons.

In summary, TIJ has succeeded in providing equal or superior ink performance (gamut/palette, sharpness, and fastness) with the introduction of a combination of dye and pigment based systems. Each ink system has some inherent advantages, and TIJ print engines can provide the necessary jetting characteristics required.

Achieving optimum print quality for text, graphics, or images is certainly a system issue. The correct amount of colorant must be delivered accurately to the right media by a mechanism and firmware that act in concert. There has been much discussion about the role of printer resolution (dots per inch or dpi). This term has been somewhat misused as “the answer” to the question of achieving high levels of prints or image quality. The ability to utilize multiple print passes, slowing the printhead in the scan axis direction, adding columns of nozzles within a printhead, or positioning the printhead at an angle are all techniques used to increase the apparent resolution. These techniques may be misleading since they cannot be used to increase real resolution. Once the resolution exceeds a certain value, the eye can no longer perceive a difference.

Resolution may help sell printers by advertising higher and higher dpi, but drop volume is a better measure of quality. When an individual dot becomes invisible and the printer has the ability to accurately superimpose many drops of colorant in any given pixel, optimum quality is achieved. Figure 2 demonstrates TIJ has led piezo over time in this important attribute. Piezo may be able to achieve the small drop volumes required, but the author firmly believes that TIJ will continue to lead the technology in this important issue until such time as there is no need for further reduction.

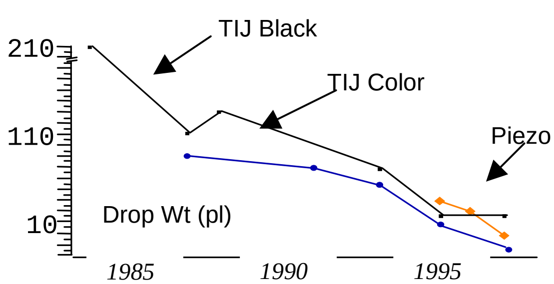


Figure 2.

TIJ manufacturers began shipping products in 1998 with eight picoliter drops. The smallest drop volume announced by desktop printer manufacturers with piezo technology is advertised to deliver eleven picoliter drops. Piezo manufacturers may be able to scale down chamber size, but have difficulty in scaling down the driver size accordingly.

A primary reason TIJ has enjoyed this leadership is the ability to scale down the firing chamber geometry with integrated circuit technology. Figure 3 illustrates the merging of integrated circuit and thermal inkjet technologies. Note how powerful the technology merging can be as chamber sizes continue to shrink in the future.

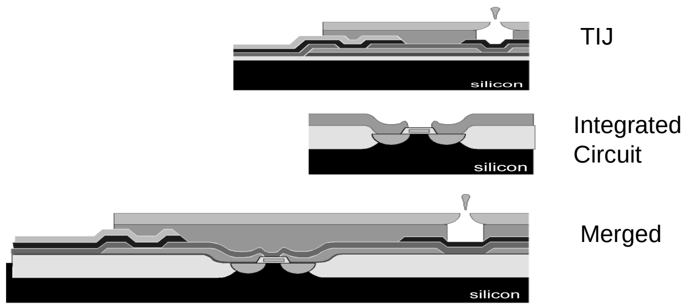


Figure 3.

Figure 4 further demonstrates drop volume reductions by showing the heater resistor and ink channel geometry on a typical printhead. The nozzle plate (note that further scaling is possible without violating established integrated circuit design rules) is also shown.

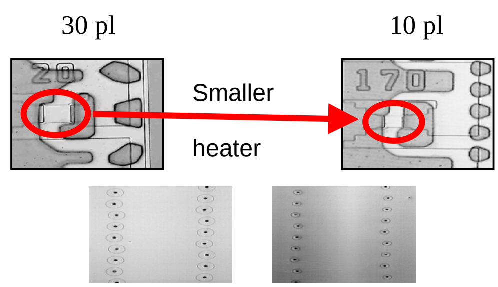


Figure 4.

One benefit of reducing drop volume that follows naturally is an increase in firing frequency. As the firing chamber is scaled down, less energy per drop is required. Since TIJ only requires a simple “square wave” drive pulse, higher frequencies are somewhat easier to accomplish than piezo which require pulse shaping for controlled drop ejection. The power of process integration is important, as higher frequencies are required. Many nozzles may be added to an existing design without adding electrical connections to the printer. TIJ has again been leading the way in nozzle count per printhead.

Print Speed

Figure 5 gives a comparison of TIJ and piezo by examining current products on the market. The nozzle count is multiplied by operating frequency to determine rate of colorant delivery. Products with one printhead for each primary are considered (multiple ganged printhead products are not considered).

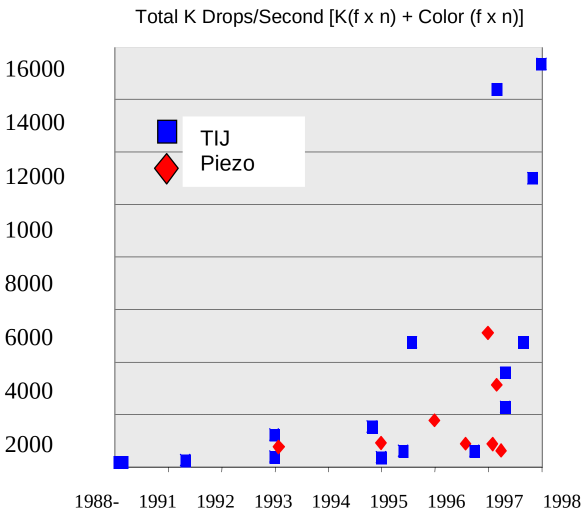
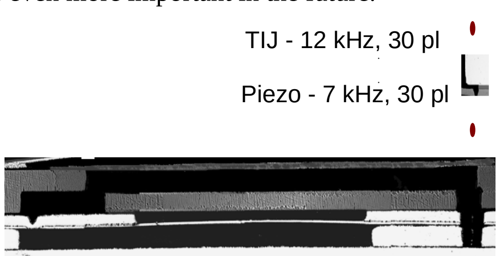


Figure 5.

High nozzle count, operating frequency, and single pass resolution are key elements to high print speed. Single pass resolution is defined as the dpi (in the paper advance axis) the print engine is capable of achieving in a single pass. If we discount the engines having multiple nozzle columns, TIJ is the leader at 600 dpi, with piezo at 185 dpi. The leading desktop models are only 90 dpi. Fig 6 (actual cross-sections) reveals the much larger chamber volume and cross-sectional area required by piezo. Both of these printheads shoot approximately 30 picoliter drops. TIJ can approach a chamber to drop volume ratio of 2:1, over an order of magnitude lower than piezo. This packing density will be even more important in the future.



Piezo chamber length = 19 X TIJ, face area = 248 X TIJ

Figure 6.

Printer Cost

Extensive use of integrated circuit technology is a key to system costs as well. Drive control electronics for temperature, dot timing, and positional compensation are all possible with integrated processes. The printing system must be optimized, and putting more “intelligence” into the print engine allows a higher nozzle count with the ability to use multiple pass printing to optimize quality while keeping overall costs down.

Much of the cost of adding nozzles for higher printer throughput comes from the electrical interconnects. This is especially true for those applications where several printheads are ganged together. TIJ has continually reduced the number interconnects to the printer while adding nozzles. Figure 7 illustrates this point.

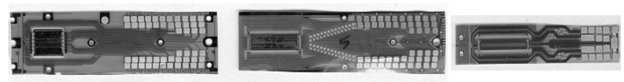


Figure 7.

Printhead Life

TIJ printheads have historically been viewed as lower cost and shorter life. Higher operating temperatures than piezo have led to more materials compatibility and robustness issues to be solved. Print quality, speed, and reliability are often at odds in the design process. A prime example is the drop volume/operating temperature relationship. Figure 8 shows a typical TIJ printhead drop weight (volume) vs temperature curve.

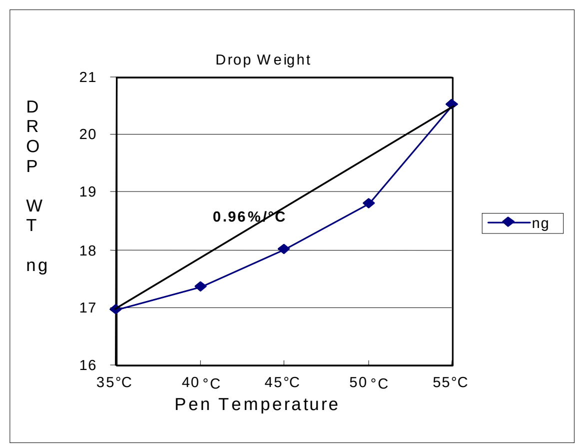


Figure 8.

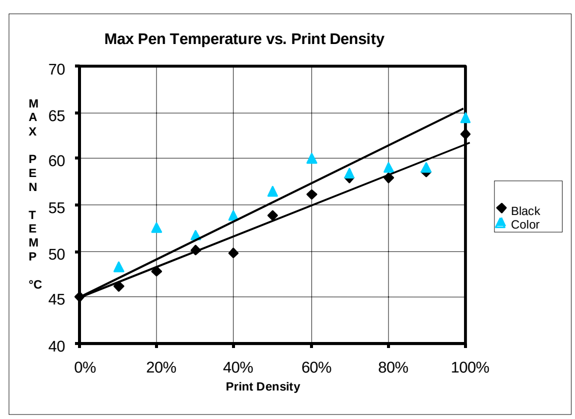


Figure 9.

In this example the drop volume increases by nearly one percent for every degree Centigrade rise in temperature.

The head temperature is determined by the ambient and duty cycle of the heater resistors. Figure 9 shows a typical relationship.

Note the lowest temperature is not ambient, but an elevated temperature. The 2000 C uses a very complex algorithm to pulse the resistors with small mounts of energy to preheat the die. The operating temperature of the printhead is maintained over a rather narrow range by preheating and adding additional heat when the duty cycle is too low to maintain the desired temperature.

The upper temperature is determined by printhead construction materials stability over time. Typical failure mechanisms such as material delamination and decomposition show a significant acceleration factor at high temperatures. With water based ink systems the "characteristic operating temperature" must be kept well below 100 degrees Centigrade to prevent unwanted premature nucleation. Uneven temperature distributions cause material stresses and reduce printhead life. Figure 10 shows a top view of a 2000C printhead where these stresses were analyzed.

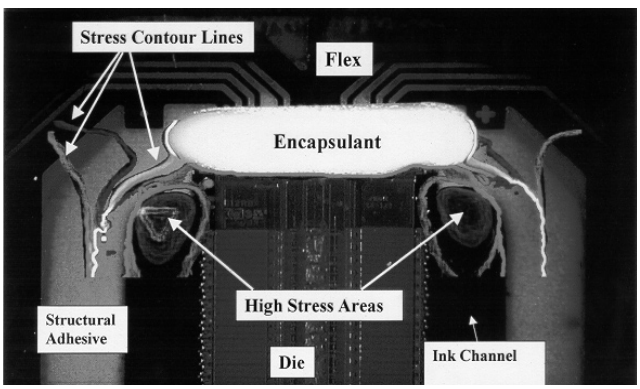


Figure 10.

Another major contribution to increasing the printhead life on the 2000C was choosing the correct material set and adhesives to withstand the temperature cycling and ink attacks over long periods of time. Particular attention was given to all surfaces in contact with ink and material interfaces. Figure 11 shows a cross section of one potentially damaging ink path through an adhesive designed to secure the die to the pen body. These ink shorts are more problematic in designs where sensitive integrated circuitry is present on the same die surface as the heater elements. New processes and testing methods were developed to ensure the integrity of these seals over the lifetime of the printer.

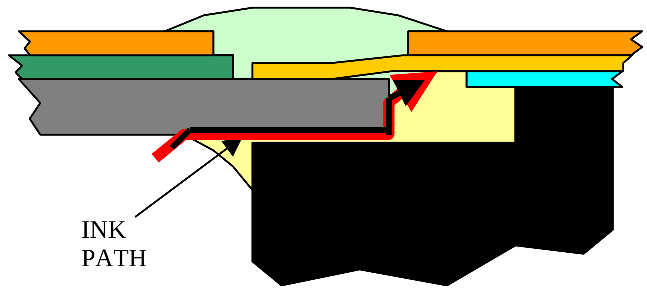


Figure 11.

Conclusions

Thermal inkjet has not only shown superiority in achieving quality, speed, and cost over piezoelectric print engines for the home and office. New materials and processes employed the HP 2000C rival piezo printhead life as well.

Biography

Rob Beeson is a senior member of the technical staff in the Inkjet Supplies Business Unit of Hewlett Packard. He has held several management and engineering positions in thermal inkjet technology since 1985, and is currently the Competitive Intelligence Team Leader. He holds 10 inkjet patents. He has a BS/MS in Mechanical Engineering from Colorado State University and has worked with several divisions in HP since 1966.