Ink Jet Printing—Past, Present and Future

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Abstract

In recent years, ink jet has emerged as one of the mainstream digital printing technologies. Although the first products were introduced in the early to mid 1970's, it was not until the late 1970's that ink jet achieved some marketing success as an industrial marking tool. In the mid 1980's, ink jet began to experience additional success as a wire matrix printer replacement in the home and office. The late 1980's has seen the introduction of ink jet printers for low cost "laser quality" black only printing and full color printing for everything from presentation graphics to high quality graphic arts. The early 1990's has seen the spread of ink jet across a wide variety of applications and environments. The full potential of ink jet is just now being realized. The last half of this decade will see the emergence of ink jet as the dominant color and low end black only printing technology. Indeed, as digital color printing demands grow, it is likely that ink jet will relegate most other printing technologies to niche markets and begin to challenge electrophotography in many high end applications.

Introduction

Ink jet printing has been much maligned over the years. Phrases like: "poor print on any paper; clogged nozzles; morning sickness; ink on the lab walls; more money spent on ink jet with less return than any other printing technology." Each of these objections has fallen by the wayside on the road to making ink jet printing a success. Although this success is do in part to all who have contributed to the technology, only a few companies which have made the long term commitment have realized any significant benefit. Regardless of any bias or pre conceived notion to the contrary, the time has come to recognized ink jet as a mainstream digital printing technology. Some will say that this is obvious and some will not agree, but to those of us who have believed and have labored in the field, this can be a very satisfying time if not an actual opportunity for expiation. The following is a brief history of ink jet printing from the early days of putting marks on paper, which were virtually unrecognizable as characters, through to the present time in which ink jet print is beginning to rival traditional offset and photographic quality. In addition to the current state of the technology, the most likely near term technical advances and predictions for future market growth in ink jet printing are included.

Ink Jet Printing in the Past

The first use of ink jet as a graphic patterning or recording device is generally attributed to Lord Kelvin in about 1873. However, it was not until the 1960's that inventors and manufacturers began to realize the potential for ink jet as a character printer. The first ink jet recording device, which was based on the continuous ink jet technology of Elmqvist and Hertz at the Lund Institute in Sweden (generally referred to as Hertz continuous ink jet technology), was introduced by Siemens-Elema in 1952.

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The first ink jet character printer appeared in prototype form in 1965. These early typewriter and teletype (engraved character impact) "replacement" printers were based on the electrostatic pull impulse ink jet technology generally attributed to Richards, Ascoli and Winston. By about 1970, the products introduced by Paillard/ Hermes Precisa of Switzerland, Teletype Corporation in the USA and Casio in Japan had been withdrawn from the marketplace. In the early to mid 1970's, Toshiba marketed an electrostatic pull facsimile printer which appears to have been withdrawn in 1978 after sales of only about 3000 units.

In parallel, the invention and development of binary and raster scan continuous ink jet by Sweet and Cummins at Stanford University led to the introduction of the A.B. Dick Videojet 9500 computer printer in 1969. This remarkable product printed 750, 5 by 7 dot matrix characters per seconds. Using this same technology, Recognition Equipment Corporation introduced the first industrial bar code and single character line ink jet printers for the postal, credit card and banking applications.

Print speed, quiet operation, non-contact imaging and all points addressability were some of the perceived advantages of these early ink jet printers. However, most of these printers were plagued with reliability and maintenance problems. These problems were primarily the result of being on the early part of the learning curve for ink jet component and ink manufacturing. In addition, the maturing development of impact dot matrix and band printers made the successful marketing of the ink jet products very difficult. As a result, only the industrial marking and document processing segment of the printer market, which highly valued the non-impact printing capability and was accustomed to preventative maintenance, was quick to pick up on this new technology.

The second generation of ink jet products for character and image printing began to appear in about the mid 1970's. This time period saw the introduction of both industrial and office continuous ink jet printers from A.B. Dick, American Can, Applicon, Bell & Howell, Burroughs, Dennison, Domino, Hitachi, IBM, Mead Digital, Neco, REI, Sharp, and Siemens. Of particular note in this group were three product firsts. The Applicon Color Plotting System, which used the Hertz technology was the first color and the first large paper format ink jet printer. The IBM 6640, which used the Sweet raster scan technology, was the first "letter quality" ink jet printer. Lastly, the Mead Dijit™ (Direct Imaging by Jet Ink Transfer) Imaging System, which used Sweet binary technology, was the first to use over 500 and then over 1200 nozzles in a single print head for supplemental printing on a web press at up to 800 feet per minute.

During the roll out of the second generation continuous ink jet products, the first generation of the impulse or drop-on-demand piezoelectric ink jet products appeared in the marketplace. The first was in 1978 when the Silonics Quietype, which was based on a seven channel Kyser and Sears (1970) planar membrane design, was introduced. In that same year, Siemens announced the PT-80, 9 channel ink jet printer. The PT-80 used the Zoltan (1970) cylindrical glass capillary technology. In 1979, Toray introduced the 8576 Kanji Printer which used the Stemme and Larsson (1970) disc capillary ejector technology as developed by Matsushita under license. During the time period from 1979 through 1984, other companies which introduced piezoelectric impulse ink jet products included Canon, Data Products, Exxon, Gould, Konishiroku, Olympia, Ricoh, Sanyo, Sharp, and Tektronix. Of particular note was the introduction of full color capability by Canon, Sharp and Tektronix. In general, these early entries were slow, required special paper and yielded marginal color quality. Exxon's endeavors into the office systems market resulted in a peizoelectric impulse ink jet printer of near letter quality using an oil based ink. The significance of this ink was that it gave acceptable print quality a larger variety of papers and it also lead to the development of the first hot melt or phase change inks. In addition to these companies, there were a large number of development pro-jects on both continuous and impulse ink jet within IBM, Xerox and many other companies, which did not result in products.

The next major event in ink jet technology was the announcement of the Hewlett Packard Thinkjet Printer in 1984. This milestone product was the result of HP's implementation of thermal or bubble ink jet technology which was independently invented and developed by both HP and Canon in the late 1970's and early 1980's. Although the printer's performance, cost and print quality were not remarkable, the ThinkJet print head marked the movement of ink jet away from the high cost, assembly intensive, discrete component manufacturing to the low cost, mass produced, batch fabrication manufacturing processes. As a result, the cost of the now "disposable" print head was low enough that it could be replaced for whatever reason with little or no grief to the user and ink jet reliability was no longer an issue. In the significance of events in the history of ink jet, this point cannot be over emphasized. From 1984 to the present time, HP has continued to improve the cost, quality and performance of their thermal ink jet line with the introduction in 1986 of the color PaintJet and the letter or laser quality DeskJet which followed shortly thereafter.

Although it was predicted that thermal ink jet would lead to the demise of piezoelectric print heads, the technology experienced a rebirth with the advent of hot melt or phase change inks. The phase change ink, which is heated to a liquid in the print head and dries on the paper by solidifying as it cools, has a significant advantage over conventional liquid inks by virtue of excellent print and color quality on almost all papers. Since hot melt inks contain no volatile, thermal or bubble ink jet is not suitable and piezoelectric has been the technology of choice. The hot melt technology was initially invented and developed by Exxon and acquired by Data Products in 1987. Since that time, Data Products, Tektronix, Spectra, and Brother have been active in phase change ink and print head technology.

Ink Jet Printing in the Present

In general, the current generation of ink jet printers can be considered to be those products which have been in-

troduced after 1990. These printers are being used to fill a wide spectrum of applications such as label, bar code, document processing, character and graphics printing, and color graphics and image printing; and in a large number of environments including industrial, home, office, educational, engineering and scientific, and commercial. Ink Jet is perhaps the most versatile technology for addressing the largest variety of printing needs.

Continuous ink jet printers are expensive to make, difficult to maintain and reliability is primarily a function of ink quality and preventive maintenance cycles. This type of ink jet has, however, performed quite well for non-contact product marking, web press supplemental printing, and high speed document processing. Inks are usually customized to fit the substrate and the application. Current US manufactures include Scitex, Videojet Systems, and Domino Amjet with system prices ranging from $20,000 to $1,000,000.

Two high quality color proofing, large paper format printers using Hertz continuous ink jet technology are being marketed by Iris Graphics and Stork. These printers produce near photographic quality at 300 dpi by the use of spot size modulation for continuous tone simulation. Although the printers are slow, the ability to produce contract proofs for a purchase price of $40,000 to $100,000 has some appeal in the graphic arts environment.

Drop-On-Demand or Impulse ink jet, for currently available products, can be segmented by driver type into either thermal ink jet, in which the drops are created on demand by applying a voltage to and rapidly heating a resistive element to create a bubble in the fluid cavity; or piezoelectric ink jet, in which the drops are created by applying a voltage to cause the deformation of a polarized ceramic to create an acoustic wave in the fluid cavity. Since thermal ink jet requires the ink to vaporize to create a drop, inks for this technology require a volatile component such a water. Piezoelectric ink jet can use just about any fluid. Although thermal ink jet requires "purer" inks to prevent "cooking" residue on the heater element, inks for both technologies have similar requirements in terms of physical and fluid properties.

The current marketplace is dominated by thermal ink jet which has about 90% to 95% of the placement share. About 50% of these sales in the last year has been printers with color capability. The US installed base of all ink jet printers by the end of 1994 is expected to be 1.8 million color ink jet units and about 5.4 million monochrome ink jet units.

The current state of the art for thermal ink jet is 3000 to 6000 drops per second per channel, print addressabilities of 300 dpi to 600 dpi, 50 to 128 channels per print head, one to four print heads per printer, and throughputs in the range of 2 to 6 pages per minute for monochrome and 1 to 4 minutes per page for color. Although the inks have improved in recent years with respect to water fastness, color quality, and paper independence, the dry time and water management on the paper is a primary problem for thermal ink jet which limits quality and throughput. Monochrome thermal ink jet utility printers are available at street prices well below $400 and color units are available for $500 to $4,000. Thermal ink jet copiers and large paper format plotters are available for $6,000 to $20,000. Canon and Hewlett Packard hold the best patent portfolio and all other manufacturers such as Lexmark, Olivetti, and Xerox are cross licensed for the technology. A few value add vendors and equipment manufactures such as Encad and LaserMaster have experienced some success in large format thermal ink jet.

Epson has been marketing a monochrome piezoelectric ink jet printer for under $300 for over a year and has recently announced a 720 dpi color version of this printer which sells for under $600. This is the first piezoelectric based product that has been able to achieve a purchase price and performance point that is competitive with the thermal ink jet products. The piezoelectric print head is intended to last for the life of the machine and the cost of the ink cartridges is less than the cost of a comparable thermal ink jet disposable print heads.

The piezoelectric ink jet printers which use solid (also known as hot melt or phase change) ink are somewhat more expensive to manufacture when compared to other impulse ink jet technologies. The ink in the print head must be maintained at elevated temperature to keep it liquid until it is projected on to the page in the form of drops where it solidifies on the surface of the paper. The main advantage of this technology is that the color quality is very good and is very independent of the paper or other print media. Adhesion to the paper and pile height on paper and transparencies of the ink were difficult issues when the technology was first introduced. Manufacturers have solved these problems by ink formulation, heating the platen, post processing the media or some combination of these solutions. The state of the art for these machines is 300 dpi to 600 dpi, 8000 to 12000 drops per second per channel, typically 96 channels per print head (48 black, 16 by 3 colors), 1 to 4 minutes per color page with retail purchase prices ranging from $5,000 to $10,000 depending of features and paper size. All units currently manufactured by Brother, Data Products and Tektronix have full color capability.

The Future of Ink Jet Printing

The future of ink jet printing will depend to a large extent on the introduction of new - faster, better, and cheaper ink jet products. This statement, which may seem obvious at first, can only come true if companies continue to develop, manufacture and ship ink jet products. The incentives for doing this are technical advancement, and of course, the money made on previous ink jet products and/or the promise of big returns on first time products. In order to predict the future, it is important to understand the role of both the technologist and the market forecaster. The technologist, which includes the engineer, scientist, and technical manager, are responsible for tasks such as technical advances, product implementation, and reducing manufacturing cost. The market forecasters try to predict the rate of product introduction based on their assessment of the state of the technology and past performance of similar products in the market

place. It is then up to the corporate management to formulate the business plan, provide the resource and maintain the vision and conviction to carry out the plan. The companies which have been able to maintain that vision and conviction over the years are now realizing the benefits and are likely to have a bright and profitable future in ink jet printing.

In terms of technical advances which are likely to be made in the near future, the process is of an evolutionary nature. Any technological "breakthrough" takes years to implement in a product line. Thermal ink jet is a good example of this process in which the original patents appeared in the late 70's and early 80's, the first product appeared in 1984 and the product line did not really mature in terms of placements and revenues until the late 80's and early 90's. Both thermal and peizoelectric ink jet have settled into a quality and cost segment that has gained market acceptance. The throughput for black only printing is competitive with the low end of laser printers, however, color throughput is in general limited by the current state of the technology. In order to improve throughput, either the drop rate per channel, the number of channels per print head and/or the number of print head per printer must be increased. All things considered, increasing the number of channels per print head (or ink color) is probably the most cost effective solution. As stated previously, the current generation of print heads have about 100 channels and increasing that number by a factor of two to four is well within reach of current technology. A factor of ten is also possible with a modular approach (multiple print heads), but other factors such as electrical drivers and connectors, and ink - paper management become far more difficult. The elusive page wide print head (~2500 nozzles per color at 300 dpi) that would compete with high end laser printers is not yet practical. Slight increases in drop rates per channel and a factor of four in the number of channels per print head are the most likely outcome for the near future. A second improvement necessary for the future of ink jet is the implementation of spot or dot size modulation for the simulation of continuous tone image reproduction in low cost ink jet printers. This will allow a much improved perception of print and image quality at lower addressabilities. Something on the order of 8 to 16 levels of spot size modulation will be sufficient for the next generation of color ink jet products. In addition to the standard wish list of improvements, agreements on color, data stream and interface standards would be helpful to all of the digital printing technologies.

Although industrial ink jet is expected to benefit from continued growth, the market forecast for monochrome and color ink jet printing in commercial, home and office environments is indeed bright. The world wide installed base of ink jet printers is expected to grow from about 3 million units in 1992 to about 10 million units by the end of 1994 and to approximately 30 million units by 1998. This represents compound annual growth rates in all ink jet market segments in the range of 25% to 50% and annual revenues in excess of 2 billion dollars with supplies revenues expected to 3 to 4 times that amount. It is also expected that the sales of color ink jet printers will exceed the sale of monochrome ink jet printers by 1997. If these trends and predictions are correct, the sales of ink jet printers relative to laser printers will improve from about 45% in 1994 to about 75% of that for laser printers in 1998.

Conclusion

Ink jet has proven to be first digital printing technology that has achieved an acceptable level of color quality at an affordable price for the majority of end users. Thermal transfer, dot matrix, dye diffusion, and electrophotographic technology have all failed to gain the high level of acceptance in the color market place that ink jet has attained. When compared with these technologies, ink jet is now the dominant color and low end black only digital printing technology. As time goes on, ink jet will continues to expand into additional printing markets and will relegate most other digital color printing technologies to niche markets and may well begin to challenge electrophotography in many high end application. **Color is the future of ink jet printing!**

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