Applications in Commercial Printing for Hot Melt Ink Jets

Linda T. Creagh-Dexter
Spectra, Inc., Hanover, New Hampshire

Abstract

This paper discusses drop-on-demand hot melt ink jets applicable to commercial printing. Advantages of hot melt ink jets, associated technical requirements and examples of commercial applications will be covered. How Spectra's technologies are embodied in a system for commercial printing will be described.

Hot melt printing in a drop-on-demand system adds significantly to the well known advantages of drop-on-demand ink jet printing. From the hot melt ink comes media independence, durability, color constancy and fast "drying." From hot melt systems come improved reliability and enhanced flexibility. Hot melt printing affords user safety and environmental friendliness. But not all hot melt systems achieve all these advantages. Spectra has worked hard to assure that our commercial systems do.

Introduction

Up to now, successful hot melt ink jet printing systems have been designed as graphic arts or high end office printers and for marking directly on products. Examples are the Tektronix Phaser III and Brother HS-1PS2. In the industrial field there is Markem's 962 system for product marking at 100 to 300 dpi. As inks and printhead designs improve, as printhead costs are reduced and as system capabilities increase, opportunities for hot melt printing in commercial applications broaden. In particular, commercial and industrial customers are looking for printing systems with high reliability, high throughputs and low cost (consumables and maintenance).

Ink/Media Interactions

Commercial and industrial printing involves a huge variety of substrates. Resolution and image quality, both of which are related to spot size, are also application dependent. High end applications such as display printing and pre-press proofing demand precisely positioned, small spots of very consistent dimensions; very special substrates are the norm and print speeds are relatively slow today. At the other extreme, volume addressing is satisfied with reasonable legibility, expects this on "papers" ranging from fine bonds to Tyvek® and requires high line speeds. With hot melt inks, spot size is dependent largely on drop volume not on substrate properties because ink interaction with substrates is dominated by freezing which is controlled by the thermal characteristics of the ink and substrate, not by capillarity or evaporation.

Spectra[1] has developed a model for the interaction of a hot melt ink drop with a substrate. Using this model, we calculate that if a drop is ejected at 125°C and travels about 1 mm, drop temperature decreases less than 1°C. At 1 cm throw distances, which may be desired for marking on products, one expects only about 5°C cooling. Even at 10 m/sec drop velocity, hot melt ink drops do not produce impacts with much spreading; the drop hits with a splat not a splash. For spots on an ambient platen, we measure spot diameters about 1.5 times the diameter of the sphere of equivalent volume. For example, a 34 pl drop yields a 65 micron diameter spot (35°C platen temperature).

The drop spread process is controlled by ink freezing. The drop spreads (assuming ink surface tension is lower than the surface energy of the media) until the thermal energy of the ink and substrate have dissipated. For a given formulation, ink density, specific heat and conductivity are fixed. Consequently drop enthalpy is tightly controlled, depending only on drop temperature. The thermal properties of ordinary substrates are similar and predictable. For example, the density of all papers falls in a narrow range, about 0.9 g/cm^3 ±10 to 15%. Thickness of the substrate is not important because, by the time spreading stops, the thermal wave has not yet reached even the midpoint of typical substrates. For a variety of papers, ink drop volume and print platen temperature kept constant, spot diameters ranged from 66.3 to 71.5 microns.

For highest quality images, substrate temperature needs to be controlled. One way of doing this is to heat the print platen[2]. The print platen temperature can be adjusted to yield the desired drop spread. With spot size control comes repeatable edge sharpness and repeatable color gamut as required for high resolution applications.

Because freezing occurs rapidly, in less than a millisecond, printing and materials handling strategies can

Originally printed in *Proc. of IS&T's Tenth International Congress on Advances in Non-Impact Printing Technologies*, October 30-November 4, 1994 in New Orleans, Louisiana.

be very efficient, utilizing all jets at maximum operational frequency. Hot melt ink jet printheads are operated commercially operated at 20 kHz with line speeds of 20 to 25 ips in the Markem 962 system.

To have printhead reliability and consistent print quality requires chemical stability at elevated temperatures because changes in ink viscosity change both drop volume and drop velocity. Just what the pot life must be depends greatly on application. A worse case scenario might be a printer which is turned on to print only one black page a day. A 5% page of text requires only about 0.04 to 0.06 grams of ink, yet all the colors in the printhead are heated to the operating point. If the printhead contains 15 grams of each color ink (similar to Telctronix Phaser III), then the user has about a years' supply of black ink and the colors are just "cooking" much of this time. Both the colorant and vehicle must be very non-reactive in order to preserve color constancy and viscosity stability at elevated temperatures. The number of dyes with good color characteristics which are stable at 120 to 140°C is relatively limited. Spectra has chosen to work mainly with pigmented inks because pigments tend to be more thermally stable than dyes. To reduce stability problems and to conserve energy, many hot melt systems cool or freeze the printhead when printing is not required. Where printers run almost continuously, pot life is much less of a constraint.

In addition, all the constituents of the vehicle must be stable and non-reactive to materials in the printhead. Additives which are volatile, solvent-like, are not useful because they can boil off, changing, for example, the viscosity. Many materials are significantly more reactive at temperatures greater than 100°C than at room temperature. As a result, ink/materials compatibility testing is vital for printhead reliability.

Commercial applications frequently require better lightfastness and waterfastness than office situatiations. The ultimate stress test may be outdoor signage. It has been particularly difficult to find satisfactorily lightfast magenta dyes for hot melt and aqueous ink jet inks. Of the colors, magenta pigments tend to be least lightfast, but sone are at least 10 to 20 times more photo-stable than magenta dyes. If the ink vehicle is not water soluble, then the ink will tend to be waterfast. For hot melt systems, dyes most likely to dissolve in non-aqueous vehicles are not likely to be very water soluble. The result is that typical hot melt inks are very waterfast compared to aqueous inks.

Today there is a generally heightened awareness of safety to users and to the environment in general. General system operating constraints such as chemical stability at elevated temperatures tend to push hot melt inks towards safe and environmentally benign formulations. Long shelf life and stability during transportation are also plusses for hot melt inks in commercial applications.

Printhead Design Improvements

A wide range of approaches has been taken in the design of hot melt printheads. Many of these use an individual transducer for each nozzle. In early designs, these transducers were bonded to the pumping chamber and actuated either as benders or extenders. The drive voltage to each jet in the array was adjusted to get consistent drop volumes and drop velocities. Even if this were done automatically using resistor trimming, it was a laborious process. Later, in some designs, a single sheet of piezoelectric material was glued to an array of cavities then diced to eliminate cross-talk. Because there is no mechanical cross-talk using the shear mode transducer, Spectra has made still another simplification: photolithographic definition of electrodes on a single sheet of PZT. The result is only one PZT regardless of the number of jets in the printhead.

The application of an electric field perpendicular to the poling field in a thin plate of lead zirconate titanate causes the PZT material to move in shear as if a deck of cards were being displaced[3]. The wall of an ink jet cavity can be pushed in or pulled out without mechanical interaction with adjacent cavities. The wall moves only tens of nanometers and the structure is very stiff which means the printhead can use inks in the range of 15-30 cps viscosity. Frequency of jet operation is ultimately limited by the time to refill the pumping chamber. For fill-before-fire jets, this time is that required to pull up the wall and operating frequencies may exceed 50 kHz.

Because there are practically no jet-to-jet mechanical interactions with shear mode transducers, jet cavities can be packed close together. One large sheet of PZT can be photo patterned for many jets and as piezoelectric properties are very uniform within a slab of material, it is not necessary to "trim" the drive voltage for each jet in an array. For 300 industrial printheads, the average drop velocity was 8.7 m/s and average drop volume 121 pl.

Commonly, fluidic pathways for large arrays of jets have been defined using thin plates of metal or ceramic. Channels and chambers can be defined with photoresists and chemically milled into metal plates, but time required to modify a dimension may be relatively long. Spectra has developed a procedure for NC machining all the fluidic pathways into dense carbon which can be precisely machined without burrs. Pressure chambers are formed on one side and flow-through passages for continuous ink circulation are machined on the other side. Connecting passages leading to an orifice plate and to an ink supply extend through the carbon plate. The coefficient of thermal expansion for carbon is similar to that of the PZT plate which minimizes stresses which might otherwise be produced by temperature variations such as occur with hot melt inks.

In some applications, the printhead can be designed to jet in fixed orientation, but many industrial applications require jetting down or in some intermediate position. In the typical horizontal orientation, the level of ink in the reservoir controls the pressure in the nozzle. To jet in other positions, a slight negative pressure (suction) can be applied to the ink reservoir. Here the pressure in the nozzle is the pressure head due to ink, less the vacuum drawn by the blower. Addition of a small fan adds little cost and greatly increases the flexibility of a static printhead system.

In Spectra's three part array, orifice packing density is limited by the amount of "land" between jets required for bonding, not by cross-talk We have found that epoxy provides good seals and rigidity for lands as narrow as 125 microns (5 mils). Pumping chamber dimensions are determined through jet design optimization which bal ances desired drop volumes, drop velocities and ink properties against drive pulse characteristics. In a recent jet printhead design, the pumping chamber is 10 mm × 0.8 mm × 0.2 mm with 0.2 mm lands. With interdigitated jets, this results in orifices at 0.5 mm spacing. We have found that 0.15 mm to 0.25 mm thick slabs of PZT as large as 10 cm by 10 cm are practical to handle with good yields in a manufacturing environment. The net is a 192 jet printhead which is capable of operating at 20 kHz with nominal drop volume of 100 picoliters and nominal drop velocity of 6.5 m/s. In a typical stationary printing application, the print swath is 16 mm and the line speed is 1 m/s to 1.8 m/s (40 to 67 ips) at 300 dpi resolution and 300 dpi addressability. Print swath height can be increased by lowering resolution or adding more jets. For example the above printhead swath height is 20 mm at 240 dpi and about 1 inch at 200 dpi. With proper filtration this class of printheads has been shown to operate with no change in drop velocity and drop volume after jetting 150 kilograms of ink.

Design simplifications produce compact arrays of jets with only three parts: PZT, carbon body and nozzle plate. Reduction of part count and simplified assembly steps are expected to increase manufacturing yields and to reduce printhead costs. As this occurs, commercial applications presently served by other printing processes may be opportunities for hot melt ink jets. For example, a hot melt ink jet bar code printer would not require costly special substrates and would have very high print speeds.

Possible Commercial Applications

Some of the natural strengths for hot melt systems are high system throughput, ability to print well on a wide range of substrates (excellent color gamut, lightfast and waterfast images), drop volume and spot size control, long printhead life, and simple printhead structures. Although one can conceive of using hot melt ink jets in almost every printing application, some commercial applications can utilize these attributes to better advantage than others.

High resolution four-color printheads are well suited to commercial applications such as large format display printing. The ink set for this applications needs a large color gamut, excellent color constancy and repeatability. If hot melt inks can be developed which are very durable and lightfast, then production of outdoor signage becomes practical. Printheads for such systems need to be able to handle large quantities of ink reliably. Although data processing time is now a large factor in system throughput, print time itself becomes important as jobs move from one-off to multiple copies of the same image. Today aqueous ink jets in an Encad-type display printer take 45 to 60 minutes to print 24 × 36 inch images. With hot melt print heads, time to print a 24 inch by 36 inch poster should be less than 10 minutes.

MICR and opaque white inks are potential applications for hot melt jet printing systems in which high viscosity ink formulations can produce stable dispersions of ferrite or metal oxide pigments. MICR applications require very durable resistant inks, high print speeds and very reliable printhead operation. Thus far, no hot melt ink has proved to be sufficiently abrasion resistant.

Addressing, labeling and bar coding are other commercial markets which should open up to hot melt printing systems as printhead cost goes down and jet packing density increases. These applications really need arrays or matrices of jets with very compact foot prints and long life. Competition is largely from wax thermal transfer which has already demonstrated compact printheads which are low cost. Drawbacks to thermal transfer are media costs and printhead life. Hot melt printheads have demonstrated both media independence and long life, but do not have, as yet, low UMC.

Franking and some other postal applications necessitate special inks to meet various government requirements. The U. S. postal service requires red fluorescence as well as limited lightfastness, abrasion resistance and water resistance but dot placement and spot size control standards are not tight when compared to office or graphic arts applications. Ability to print 1.2 inch high swaths at the rate of 300 envelopes/minute with resolutions greater 240 dpi are desired for high end franking systems. This requires ink which "dries" rapidly and a printhead with about 14 kHz operational frequency, both attainable with hot melt ink jet printheads.

Conclusion

Hot melt ink jet technology offers solutions to today's and tomorrow's printing opportunities whether in an industrial venue or in the office or in the print shop. Ink formulations and printing systems should be tailored to the application to actually achieve image quality, product cost and cost-to-consumer targets. Just as no single ink jet printing system is best for all imaging markets, there is no single hot melt system which is ideal for all applications.

Acknowledgments

This paper would not have been possible without the help of many people at Spectra. In particular I want to thank M. K. Walters, E. R. Moynihan, C. W. Spehrley, and N. P. Hine for experimental results and technical support.

References

1. Spehrley and Wright, *IS&T/SPIE*, February 1994.
2. Spectra, US 4,951,067.
3. Fischbeck, US 4,584,590.