The Hurdles to the Development of Digital Imaging on Textiles and Strategies for Jumping Them

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Introduction

A number of physical, chemical and economic obstacles are challenging those who are developing direct digital printing technology for textile applications. In the following pages, we will identify and describe those hurdles and strategies for overcoming them. IT Strategies has gathered this information from interviews and avail-able literature. The report will focus upon direct digital printing of textile. It will, however, compare and contrast other technologies, such as non-direct and analog textile printing, with direct digital to better understand its competitive challenges and cooperative opportunities with them.

Technical Hurdles And Challenges

Introduction: The Wish List

Textile printers want a way to decorate fabrics with the full spectrum of color quickly, with the greatest quality, least possible expense, and the greatest flexibility to meet all possible customer demands. Bolt fabric printers want to print with the speed, color range and quality of twelve color cylinder screen printing presses which print at a cruising speed of 90 meters per minute. They want the prints to have virtually no hand and to feel like printed colorant is indistinguishable from the fabric like dye screen printed silks. Cut piece printers want the speed and output quality of belt screen printing presses. Garment printers want production rates of 400 to 600 multi-color prints per hour plus photographic reproduction quality, and to be able to print on all fabric colors including darks without losing color vibrancy. All want to eliminate film positives and negatives, screens and plates, screen and plate preparation, exposure, developing, masking and registration and press preparation. Most are also eager to eliminate or better control ink mixing. Current digital technology can satisfy some of these wants. Technology developers will take months to satisfy some others, while one may have to wait generations for others. The following chapter examines a number of the technological challenges which confront digital textile print technology developers.

Impediments And Challenges

We find hurdles for both the digital textile systems developers and their potential users. The developers face the particular hurdles of color calibration and management, print quality, production speeds, materials handling, and chemistry, along with the more universal hurdles of personnel and capitalization development, cost containment, marketing, and customer service. We will focus on the particular, leaving the universal issues to educators on business management. In addition, digital printers will face the hurdles of customer acceptance of digital output quality, educating ones textile artists and designers to understand the graphic implications of the specific digital system and its opportunities, educating ones marketing staff to adjust to unit pricing replacing volume pricing, selecting and training digital imaging systems operators, planning, and paying for it all. For this examination, we will focus on the hurdles which digital textile printers, inks and systems developers will face.

Color Control—Most color ink jet systems produce three or four color process, cyan, yellow, magenta, and black (CYMK) color. This system can not produce the full range of visible color, but can create a large potion of it. CYMK digital printers combine these colors in various patterns and percentages of coverage to reproduce intended colors. By utilizing color calibration software one can create an accurate color baseline from which to manage printer color output. A quality color management program and operator training will enable one to maximize reproducible color gamut. Environmental conditions like temperature and humidity can affect the hue, value, and intensity of the inks. In order to reproduce specified colors consistently, one must either maintain a constant printing environment or adjust color variables to produce a consistent result, especially for electrostatic sublimation printing. Since fabric designers want printers to reproduce the colors they select exactly and since they are wont to chose colors outside the gamut of CYMK, digital print system providers will encounter the control and expand the gamut challenge early in development. The current 4-color process system will not satisfy all of the demands of textile designers and their customers. Designers and customers are demanding greater color range and consistency. Print providers are responding to these demands by investigating alternatives to four color process. These forces want the flexibility and accuracy of spot color, the range of expanded gamut systems, such as hexachrome, hifi color, CYMKRGB. They want the vibrancy of fluorescent colors and the permanence of metallic oxides.

Print Quality—We can divide print quality into issues of image appearance and image performance. The former includes image resolution, reproduction pattern, edge sharpness, and color accuracy. Image performance focuses on a print's effectiveness of its bond to the fabric, fastness to washing, dry cleaning, rubbing and exposure to sunlight, and hand.

Resolution—This term refers to the ability of a printer to reproduce fine detail, as well as the degree to which that detail is reproduced in a print. Generally, the number of dots per inch (dpi) a print device produces to create an image indicates resolution. But, for ink jet, the number of droplets used to create a dot will affect resolution. One or more than one droplet can create each dot. Ink jets form dots from one, two, three or as many as 31 droplets. The greater the number and the smaller the drop volume, the finer the apparent resolution. Many ink jet printing devices employ multiple passes to increase color density, eliminate banding and improve resolution. Higher resolution usually involves more and smaller ink jet orifices. Generally, the smaller the diameter of the orifice the smaller the volume of the droplet. A recent development will, however, allow smaller droplets from larger orifices. But usually, when one decreases the orifice by a half, the droplet volume decreases to one-eighth (0.125) the original. By decreasing the orifice to a third, the droplet decreases to one-twenty-seventh (0.037037). As you decrease ink droplet size, you reduce ink deposit and color intensity of your image. Also, the greater the resolution, the longer it takes to cover the same area. Also, the smaller the droplet, the greater the frequency at which you can produce them. Also, the greater the ink flow and fluid pressure, the greater the ink droplet volume.

Determining and printing the magic combination of resolution and drop size presents a formidable task for textile ink jet printing. What is the best resolution and droplet size for printing on textiles? If the customer can not see or is not displeased with a digital printer's telltale identifying signature, its image artifacts, we are in the land of acceptable resolution. In determining desirable resolution, we also need to consider the character of the fabrics we are printing. Ideally, the unaided eye should not be able to see the dots that create the image from the intended viewing distance. Lines, text and edge contours should not betray sawtooth or ragged edges unless intended. Gradation of colors should appear as seamless transitions, instead of distinct dots. The tighter the fabric weave and the finer the tread, the higher the resolution necessary so as not to see the character of the printing. Coarser and looser woven or knitted fabrics may not require as high resolution since the character of the fabric will hide more. Coarser fabric will generally require the greater deposit of ink larger droplets provide. Since viewing distance will vary according to application, ideal resolution will vary as well. Coarse rug fabric normally viewed from a distance of 1.2 to 2 meters only require resolution of 20 to 30 dpi to obscure visible dots and win customer acceptance. Banners viewed from more than 5 meters can present the illusion of continuous tone photographic imagery at even low resolutions. While fine broadcloth used in making shirts viewed at about 0.4 meters will require resolution between 180 to 300 dpi to obscure telltale ink jet dots and create effectively the same illusion. 360 dpi creates the impression of photographic quality on fabric. The overwhelming majority of textile applications will not require a resolution greater than 300 dpi. Most will benefit from lower resolution in the 200 dpi range and larger drop volume. This combination can produce greater color saturation and higher production speeds than the higher resolution devices that better address customer demands for the desktop and wide-format graphics markets. These preceding estimates represent the subjective observations and evaluations of a small number of individuals who are studying digital imaging for textiles.

The most effective resolution is one the customer embraces and buys. Often the customer one needs to satisfy is the design creator. Designers will focus more closely than the general public. Designers will test digital textile printers' abilities to print both high resolution and intense, wash fast and saturated color. Fabric printed at 120 dpi satisfy most non-designer customers as acceptable for T-shirt decoration. For apparel textiles, I have found that resolution of 180 dpi or greater win virtually universal designer approval. Broadcloth fabrics printed at 300 dpi on the Stork proofing Hertz continuous ink jet is somewhat sharper than the same fabric printed with the same design on the Stork rotary screen printing textile printer.

Reproduction Artifacts—Printing methods have signatures. A trained eye can detect the way an image was made from the character of the print. For instance, you can discover the telltale signature of a letterpress in the incised stamp of its prints. Screen printing will often betray a saw-toothing on image contours. Generally, the more recognizable a print technology's signature or artifact, the less acceptable to designers and customers. Digital printing technologies also manifest signatures which digital developers struggle to erase. Most digital printing technologies manifest banding, a regular apparent striation pattern across a prints surface which records the direction of the relative movement of print heads to print surface. Ink jets droplets may splatter somewhat when colliding with a fabrics surface creating a fussy corona around the drop dot.

Edge Sharpness _ Maintaining the definition of a contour as distinguished from its surroundings is edge sharpness. A viewer looks for edge sharpness around type, lines and definite geometric forms and shapes. The capacity of a printer to target ink without scatter or spatter enables it to achieve edge sharpness. Usually, the finer a printer's resolution, the better the edge sharpness.

Color and Gray Scale Gamut—The range of the visible spectrum that one can reproduce is color gamut. The range of color that a group of primaries or mixing colors can reproduce is that group's color gamut. As mentioned above, the gamut of CYMK 4-color process does not include all the colors of the spectrum. The challenge for digital printing is to be able to reproduce all of the colors the market wants. For instance, the gamut of CYMK does not include many company logo colors. Since those companies want their colors reproduced exactly, digital developers will have to move beyond 4-color process to include spot colors or expanded gamut. Gray scale refers to the capacity of a printer to reproduce gradations of value from white to black. The greater the range of gray scale, the greater the depth and photographic quality of the image.

Bond & Fastness—The relationship of one thing to another is their bond. The more intimate the relationship, the more likely it is to endure the trials it will experience. Materials can adhere to each other with varying degrees of intensity, from physical contact to chemical molecular connection. The nature of the bond will affect the fastness and usefulness of the image. Usually, when we print a fabric, we want the image to stay where we put it for its usable life. We want it not to fade, rub off, transfer to other garments in washing, or disappear when dry cleaned. Some types of fabrics, prints, and inks will not survive all these rigors. Some inks will dissolve when dry cleaned while other will not survive machine washing. Hence, we have garment care labels to help us not unwittingly destroy what we wear when caring for it. A digital textile printer's output prints must pass either the appropriate AATCC or ISO tests for wash, crock (rubbing), dry cleaning, and UV-sunlight exposure fastness to win market acceptance.

Hand—A fabrics feel, its degree of stiffness is called hand or handle. Printing with pigments tends to stiffen a fabrics hand, while print with dyes will manifest virtually no hand after post-print treatment. Ink jet printing with well formulated pigment inks can produce images with almost no discernible hand.

Material Handling—Most textiles lack the dimensional stability to resist movement. In order to print colors and images in consistent register one needs to eliminate movement or, at a heightened level of complexity, control and compensate for it. Current analog printing of fabric bolts, cut pieces, and garments involve adhering fabric to a belt or rigid platen that moves under the printing mechanism. One can adapt these or similar material handling and transportation strategies for textile digital printing. The degree of difficulty of the material handling increases when one tries to combine digital and analog functions, or printing and cutting on the same production line. Ideally, each part of in-line production should proceed at the same rate and mode. Mixing continuous and intermittent processes will compromise production efficiency but may be unavoidably necessary to accomplish ones goal. A production line will move only as fast as its slowest process. If one function needs to be intermittent, than all elements should operate synchronously with the intermittent process. Intermittent modes usually have two phases of operation, one when the production line's forward progress is stopped and the other when moving. For example, in a T-shirt printing production line, during the halted phase, the machine could remove lint from garments and then print them. During the moving segment, a spray device coats empty platens with adhesive and a curing unit cures the garment image as the garment platen. Of course, other rhythmic patterns of intermittence timing are possible, but one must organize all the elements of production so that they follow the intended choreography.

Production Rate—When potential purchasers of digital equipment are asked what more do that they want from a wide-format printer, one usually hears words like "more speed", "faster", and "increased production rates". In its present configurations, digital printing is significantly slower than competing analog reproduction methods. Whereas analog printing methods contain the whole image on their plates or screens, digital printing methods must build the desired image dot by dot, pixel by pixel. Digital textile printing can win the production rate race over digital for sample and very short run printing due to its lack of prepress, press set up and tear down time. But analog's superior press rates win for medium to long production runs. In order to compete with the current analog textile printing technologies, digital developers will have to greatly increase the throughput speeds of digital textile printers without compromising print quality or pricing the printer out of the market.

One strategy for improving speed would increase the number of print heads. When Idanit designed its 162Ad piezo wide-format printer, it incorporated an array of almost 5,000 heads to produce a significant increase in throughput speed. The increase in the number of heads printing also increases the degree of difficulty for head alignment, registration and compensating for incidents of head failure. One can use either fixed or traversing (scanning) modes. Fixed arrays provide fast production. Their configuration matches the single pass per color continuous material flow that web textile bolt printing favors. They will produce visible banding unless head alignment or print patterning compensates for it. The Toxot multi-level continuous ink jet heads, which can print not just to a point but a length along an axis, can overlap bands to eliminate visible banding. Traversing arrays can also compensate for banding with multiple passes and algorithm adjustments. As the size of the array approaches the width of the print, the faster the print speed.

As the mass of the array increases the greater the inertia to overcome and control when changing rate or direction of movement. The material delivery system could also move to increase production rates. Drum material delivery configurations allow traversing heads to move in one axis while the fabric carrying drum rotates in a perpendicular direction. Controlling and coordinating two axial movements simultaneously may add to engineering and software complexity, but developers have already addressed this issue. Existing drum arrangements do not permit continuous textile throughput. Printer operators have to attach for printing, then, remove it. Drum width and circumference limits print and piece size. Printing continuous bolts of fabric will likely involve conveyor belt material delivery with either intermittent movement for traversing print heads or continuous for fixed array. The greater the number of arrays the greater the difficulty to achieve and hold register and consistent images. Increases in process rate will likely require systematic complexity which will decrease reliability. Systematic complexity usually results in increased cost. If the increase in production does not more than offset the increase in cost, the hurdle will have grown higher. Also, a faster machine will print more textiles. A company's marketing efforts may have to increase to feed it. A faster machine will cost more and its economic demands will not tolerate it being left idle.

Drying And Curing—Inks jet inks will often form puddles after being deposited on surfaces whose rate of absorption into the substata is less than the rate of deposit minus the rate of evaporation. Puddling can destroy an image, produce undesirable and inconsistent blending of color and handling difficulties. Since most textiles readily absorb low viscosity liquids like ink jet inks, the puddling phenomenon appears mostly on coated textiles with reduced imperviousness. The rate of drying so as to prevent puddling and undesirable color blending will often limit a digital imaging systems production rate more than its imaging speed.

Reliability—We can define reliability for digital technology as its ability to produce desired results consistently. Some technologies are more reliable than others. Thermal ink jets suffer from kogation, the hardened build up of ink around ink jet orifices, and thermal resistor fail. Both of these produce head failure and the waste of fabric, time and money. Desktop thermal ink jet manufacturers employ a number of strategies which address areas of unreliability resulting in highly reliable printers. Digital textile printer developers need to address the unreliable characteristics of a process to eliminate or circumvent them. Processes that have fewer moving parts tend to perform more reliably. Inherently complex electrostatic printers and copiers with many moving elements tend to fail and require maintenance more than a thermal transfer printer which has fewer moving parts. Even the simplest device will fail if not made with quality and its end use in mind. In today's marketplace, business people presume and insist on the presence of total quality control procedures in manufacture of devices like digital printers.

System Integration—Many digital developers have concentrated on one or a few aspects of digital printing development. But successful digital textile imaging will only come with integration of all the necessary parts, from design to finished product. If the art does not account for the characteristics of the printing device and the media, if the digitally generated art is not compatible with the print driver software, if color separation lacks compatible software to calibrate and manage the printing process, if the material transportation mechanism is not fully integrated with the printing heads, if the inks tend to clog ink jet orifices, if any of the parts are not integrated into a workable whole, the system will not print successfully. From raw material suppliers to customers, the participants must communicate, cooperate and coordinate if they are to reap the benefits of their labors. A series of alliances among the producers of the various parts has formed and will have to continue to form. Every system will require an integration manager to tie it all together.

Chemistry—Ink jet technologies require very low viscosity inks. Rug printers have been using inks from 100 to 400 cps. But most drop on demand and continuous ink jet printers that developers are designing for textile printing require inks with lower viscosity. CIJs use inks between 3 to 6 cps. Many DOD inks print at 10 to 20 cps. Creating inks that approaches the consistency of water, will not clog ink jet orifices, will adhere to fabric, resist crocking and fading in sunlight, retain color fastness to machine washing and dry cleaning, produce the desired intensity, value and hue, possess the necessary conductivity (for stimulated CIJ), are not flammable, explosive, or deleterious to workers and environment is a challenge. Most dye-based ink jet graphics inks fad under outdoor exposure. Some dyes perform better than others. But when one want fabric to resist fading to sunlight exposure, pigmented inks provide a greater likelihood of success. Making pigmented inks that will print through 10 to 30 micron diameter orifices without creating pigment "log jams" presents a not inconsiderable challenge. The fabric printing industry wants an ink that produces the soft hand of dye, the fad resistance of permanent pigment, requiring little or no post-print processing.

Environmental Controls—One of the biggest factors governing consistent color reproduction for electrographic printers is maintaining consistent temperature and humidity. Lint and dust can block print heads and foul prints. Print producers must maintain digital textile equipment in temperature controlled lint and dust free environments.

Consistent Color Supply—In order to produce consistent color reproduction, one needs a consistent supply. Variations in fountain toner quality in electrographic printing will affect color consistency. Flocculated ink jet inks can clog orifices or produce inconsistent color. Maintaining ink and toner consistency and quality presents system developers with on-going challenges.

Learning Curves—Some needs to train the people who will design for the new digital textile printing technology. Someone needs to instruct the operators and managers. Someone needs to re-educate the marketers and salespeople as to the opportunities and limitations of digital print technology. Someone has to train the trainers. Proper training will reduce the learning curves and bring profitability much sooner.

Competition—The performance of digital production printing systems will either justify segments of the textile market paying their prices or justify delay until performance improves. Digital textile printer manufacturers will struggle to compete against existing analog technologies that print faster and better. The boosters of digital textile printing have overestimated the costs associated with prepress, press set-up and tear down for analog printing. Printers who strive to constantly improve their processes will find ways to make screen printing perform. Print prov-iders will use digital textile print technology either in conjunction with analog printing or in stand alone mode for digital's unique capabilities, such as customization and on-demand delivery. Digital will begin to compete with analog printing methods for standard production when developers can meet customer needs better than analog methods. Digital methods do not have to match conventional printing's run rates. Digital print devices just have to match the production rate of the manufacturing process to which they are in-line. The success of the digital printing device will be in its ability to satisfy customer needs profitably. Its remunerative production should more that off-set its operational and amortiztional costs. Its prepress time and cost savings can offset the analog run rates for most production. For small to medium sized garment printers, that point arrives with the $30,000 digital printing device that can print 140 multi-color images 0.33 × 0.33 meters per hour at production and consumables costs of $.50 or less per shirt. These printers want the system to print dark as well as light garments. For many bolt printers, the arrival of a multi-color digital printer that can print 120 running meters of 1.3 to 1.5 meters wide bolts per hour, cost $500,000 or less at production costs of $.20 per square meter will stimulate industry's interest and adoption. In-line cooperation of analog and digital technologies can marry the advantages of both to satisfy demand for customization and low costs.

Digital Strategies For Overcoming Impediments

Both ink and equipment developers are devising strategies for jumping the digital textile hurdles of color control, print quality, material handing, speed of production, reliability, system integration, environmental controls and chemistry. Some of these will fail while others win inadequate market acceptance. Developments in digital desktop, wide-format, and industrial arena will translate to textile printing application. But only those that meet textile's performance requirements will succeed.

Color Control Strategies—Any digital system that prints colors consistently will have color calibration and color management coordinating its raster image processor (RIP) or scan and print driver. Color matching is moving from an art to a precise science. Printers are now able to measure the visible characteristics of a printed color and reproduce it exactly. The team of ink formulator and printer will match by wavelength and reflectance using spectrometer and densitometer. Color calibrated spectral analysis of color system elements will establish a baseline from which to expand the gamut of 3 or 4-color process, hexichrome, hi-fi color, red-green-blue (RGB), CYMKRGB and spot color mixing. Color management software will use this information to manipulate the mixture and create the separations of elemental colors in the RIP or scan and print driver to realize the desired colors. Printer manufacturers are increasingly including color calibration and color management software along with a RIP or printer driver. Postscript RIPs have become the standard for high quality text definition. Hardware RIPs have advantages for speed. Ink manufacturers will play a key role in supplying certified spectrometer calculated color matched inks and assisting printers in expanding the palette of their print devices. Software developers and integrators for electrostatic sublimation dye transfer printing, such as Cactus, Visual Edge, and Onyx, are creating color management and color calibration programs to package with their other software and hardware offerings. Digital equipment manufacturers have begun to offer more than four ink cartridges and print heads. Raster Graphics offers its system currently with five color capacity, albeit the extra print head is often dedicated for a clear varnish. Oce has announce a new a seven color electrostatic color copier/printer imaging unit for RGBCYMK. As mentioned previously, Konica plans an eight color ink jet. Other digital equipment developers will soon offer ink jets and electrostatic printers that permit 5,6,7, & 8 color printing. Ink manufacturers have begun to offer colors beyond CYMK. The palette will increase to satisfy the customer. Expanded gamut systems like hi-fi color, and hexachrome will replace CYMK for dye sublimation printing and will likely dominate digital bolt cloth printing. While we can expect growth of expanded gamut for digital garment and T-shirt printing, spot color screen printing is likely to continue to satisfy most textile printing applications for the near future. But if the textile market's demand for consistent and specifiable color increases, we should see growth in those digital technologies which can provide it.

Print Quality Strategies—The digital developers have steadily improved print quality for desktop and wide-format printing. They have sharpened resolution, improved color density, provided outdoor durable and wash fast inks, eliminated significant visual banding, minimized splatter, and expanded gamut. But what works on paper can fail on cloth.

Resolution—A critical issue for digital textile printing is the selection of resolution and ink volume to suit the character of particular fabrics and applications. The critical question is what can customers see and what will they accept? The trained eyes of print professionals and designers will see and object to resolution artifact at finer resolutions than the final purchaser. Since achieving finer resolutions with a technology results in slower production speeds, print providers will want to consider the economic constraints along with those of print quality. 180 to 300 dpi resolution will satisfy most customers for apparel textiles. Higher resolutions and higher numbers of finer drops per dot will permit increased gray scale range, but at the expense of production speed and colorant fiber penetration.

Fabric treatment and coating can improve apparent image quality and reduces the amount of ink deposit necessary to cover the print surface. But this is at the expense of fabric hand. Fabrics tend to offer a very forgiving surface for imaging.

Reproduction Artifacts—Each reproduction technology creates its own artifacts. Strategies for eliminating or reducing the visibility of artifacts will vary by type of print device. But problems like banding afflict most digital print methods. Banding results from the action of the printer which varies ink or toner deposit in a pattern of striation. Multiple print head passes and software adjustments can alleviate this problem when using a scanning head. In systems employing fixed arrays, a number of strategies can compensate for banding. One would involve moving the material handling device to accomplish the multiple pass approach of the scanning head. Another would use multiple fixed arrays for each color to simulate multiple passes. Finally, Toxot's multi-level continuous ink jet heads can overlap spray patterns so as to eliminate banding.

Edge Sharpness—Improving the sharpness of lines focuses on the addressability, the capacity of the printer to target ink to a specified location on the print surface. The strategy of employing heads that generate higher frequency finer droplets will product sharper edges. The shape forms in images printed with the fine droplets and high frequency of Hertz continuous ink jet technology demonstrate this. Excessive unaccounted movement of traversing heads, material carrying drums, belts or flatbeds, such as can occur with changes in direction, acceleration or deceleration, can produce image distortion, particularly in the direction of movement. Algorithms governing the deposit of ink to create the image need to precisely account for momentum, changes in direction and speed.

Color and Gray Scale Gamut—The greater the number of droplets a print head can address to its print grid, the greater the number of possible shades of gray and tints of color. Color management software enables one to expand ones gamut slightly or to shift gamut. Ink purity will help avert muddiness that can occur when impure colors mix. Expanding the number of colors printed to include hexachrome, CYMKRGB, hi-fi, and spot color will greatly expand gamut and tonal range.

Bond and Fastness—For pigment printing, manufacturers have employed polymer binders that will adhere to fabric and remain fast when subjected to sun light, washing, dry cleaning and rubbing. Developers have designed water-based, solvent-based, and UV curable pigmented inks to print on textiles. For thermally or UV cured polymer inks, one must monitor energy levels to insure total cure and resulting fastness. For dye printing, adhesion and fastness will vary according to type of dye, fixing, and fabric. Fiber reactive dyes have excellent bond and fastness to cellulosic and protein fibers while disperse dyes bond well with synthetic non-cellulosic fibers. Choosing inks and dyes that bond chemically like fiber relatives and sublimation dyes will insure excellent crock resistance and wash fastness. UV filtering additives can decrease dye susceptibility to UV degradation and increase its fade resistance to sunlight. Ink jet pigmented inks that imbed and adhere to fabrics can offer more resistance to fading under sunlight exposure, and good resistance to machine washing and crocking. One can also coat fabrics with a variety of substances that will absorb and filter UV radiation, improve crock, washing, wear, and flame resistance.

Hand—Ink jet printing on fabric with pigmented inks produces a hand which approaches that of dye printing. Dye based inks usually require curing and post treatment including washing to fix the dye and restore fabric hand. One of the strengths of ink jet textile printing is its superior hand. Digitally imaged dye sublimation transfer prints also preserve the hand of the fabric. Electrostatic and electrophotographic toner transfers and thermal wax transfers inform the printed textile with objectionable increased stiffness. Much of this stiffening comes from the coating in the transfer paper which transfers to fabric as part of the transfer action. Modifying these coatings and using those which transfer the least can help reduce the problem. One approach images on papers with minimal coating then coats the image and transfers with very high pressure can virtually eliminate the hand problem, but adds considerable labor to the production process.

Material Handling—Most textile fabrics lack dimensional stability. They will change size and shape in response to handling and environmental conditions such as temperature and humidity. Printing multicolor images requires that one control and compensate for any movement of fabric with respect to printing actions. Material handling machinery must transport and hold the fabric to a dimensionally stable carrier such as a rigid platen, flat bed or belt. One will usually hold the fabric to the carrier with a table adhesive or, for some non-porous fabrics, vacuum. Most single-ply textile automated computer controlled cutting conveyors employ vacuum to hold the fabric to the cutting surface Loading and unload-ing fabric and garments presents particular challenges. Continuous web printing of bolt fabrics require that the device place the fabric firmly flat on the print carrier where the imaging device will print it. The fabric edges must run straight, parallel and align with the print action. Device developers must coordinate the action of the print device with the movement of the material handling device. Com-puter controlled movement will involve AC servo motors and platen locking devices for printing involving inter-mittent movement. Character recognition, edge tick marking, laser markers or locator technology can help align textile with print action.

Digital garment, cut piece and bolt printing present different movement control challenges. Vacuum that is used to hold fabric for single ply cutting will not hold the tolerances printing demands. Adhesive hold fabric adequately. Salvage pin restraints do not retard the fabric movement adequately.

Garment loading and unloading devices already exist that can automate printing on digital platen printers like the one Emblem intends to produce. M&R holds a patent for a mechanism it produces which transfers printed cut pieces from belt printer to curing conveyor. Printing and cutting inline presents a complex of material handling problems which might require a complex of strategies to solve.

Production Rates—When one analyses a process to discover how to improve its through-put, identifying how it uses time will often reveal ways to hasten the process. Digital printing consumes time in using Raster Image Processors (RIP) or scan and print drivers to tell the printer what to print and in the action of the print device adding color to the print surface. The feeding or placement of the material so as to be imaged and its removal also consume time.

The battle between RIPs and scan and print drivers will likely result in new products that attempt to achieve the fast processing and low memory burden of scan and print drivers with the editing flexibility and typography edge definition that RIPs offer. Scan and printer drivers will own an increasing segment of low end imaging up to 36 inches, while RIPs hold the more complex higher and wider market segment. The software mavens need to tweak Postscript to produce more manageable smaller faster files without loss of functionality. RIP time comprises half of the speed problem for sample prints and proportionately less for multiple prints. For example, the RIP time for a single print on an Encad Novajet III printer can equal the print time. Developers are already responding to these concerns with improvement in RIP speeds. Faster central processing units and larger memory will further address the speed concerns.

In addition to improving RIP times, one can increase production speeds by clustering print heads. As one adds heads that are printing the same color, the faster one can print. More print heads also increase the probability of a head not printing and misaligning resulting in misregistration. Increase complexity often increases the likelihood of failure. The significant increase in speed, however, that grouping print heads can effect more than justifies increased complexity. One can readily align heads successfully with existing devices and protocols. Desktop printer manufactures, for example, now employ optical character reader technology to align heads.

Drying And Curing—Since the puddle formation phenomenon with ink jet output relates directly to deposit, absorption, evaporation and drying rates, one can modify one or more of these to the extent necessary to eliminate puddle formation. One can accelerate the slow evaporation rate of water, of which most ink jet ink are primarily composed, with the addition of convection or radiant heat. Depositing finer droplets, reducing the relative humidity in or immediately after the print area will also facilitate evaporation. One could also use solvents with higher evaporation rates than water either in combination with water or replacing it. One could also eliminate solvent in part with the use of UV (or other radiation) curable water-soluble inks or altogether with 100% solid UV curable inks. Phase change type piezo printers can also obviate puddling. Such curing alternatives can help to eliminate other failure modes like some forms of nozzle clogging. Toxot has developed a UV curable water-soluble ink which posses adequate print and fastness characteristics. Another strategy would be to increase the capacity of fabrics to absorb liquid ink or the ink's capability to be absorbed.

Reliability—Since complexity can decrease reliability, simplicity should increase it. Systems with fewer moving parts tend to fail less often. Manufacturers which implement total quality management programs can increase the reliability of their products. Maintaining, cleaning, lubricating, and recalibrating equipment improves reliability. Locating a printer in a dust-free controlled temperature and humidity environment will also improve the reliability of its operation.

In addition to these general strategies for improvement, reliability problems plague some digital technologies more than others. Ink jet heads with larger orifices tend to fail less. This despite the fact that the smaller the orifice of a thermal bubble jet, the greater the force of droplet ejection. Employing finer particle sized pigmented inks which remain in dispersion or dye-based inks with no impurities will enhance printer reliability. Kogation plagues thermal bubble jet printers. Similar orifice clogging can trouble piezo heads as well. Keeping dust and lint from the print head orifices will prevent fabric waste and reduce frustration. Of course one could maintain printers in clean room environments. But textile substrata will usually transport considerable lint. Scitex Iris attempts to control its lint problems by coating the textile fabric with a fabric sealant which encapsulates fibers from dissociating themselves from the fabric. One could also maintain about a 50% relative humidity or higher or using application appropriate ion generation to eliminate static and precipitate dust and lint way from print heads. Desktop manufacturers have improved the reliability of these printers by replacing or cleaning these types of heads regularly. As one switches to permanent heads for larger volume production, one must find on-going strategies. Increasing the force used to eject droplets from drop on demand ink jets can also help to open clogged orifices. Idanit continually pulses its Dataproducts's piezo heads into a blotter pad to prevent orifice clogging. Solvent-based inks will also help keep nozzles open, but can increase fire hazard, and worker and environmental exposure to hazardous chemicals. UV or other radiation curable inks will improve reliability in addition to eliminating puddling and replace large thermal curing units with less real estate hungery UV curing devices. Other strategies for maintain-ing orifices in operable condition can involve a cleaning cycle, needle valves or covers, and ultrasonic vibration. Improvements in resistor coatings would also extend bubble jet life and increase its reliability. Manufacturers could also adopt strategies which mimic the more reliable continuous flow.ink jets as Idanit has done with its continuous pulsation of its heads.

Continuous ink jets have a greater reliability than drop on demand ink jets despite their increased complexity. Since ink flows through the reservoir orifice continuously, it lacks the opportunity to clog.

System Integration—A digital printing system contains many parts and elements that users want to work together seamlessly. Since many digital developers have not vertically integrated the manufacture of all elements of their digital systems, they must rely on other manufacturers. The physical digital textile print system is part of a large system which includes raw material suppliers to end users. All of the participants and partners in this large system of benefactors and beneficiaries of the system's development must communicate germane information to the relevant partners. Communication will facilitate system development, installation and adoption. An integrator can insure that all of the parts work together. Printer manufacturers are best situated to perform this role. The integrators will achieve greater market success if they communicate with their end users to ascertain their wants and needs.

Inevitably, that will include instruction and training for the operation of the print device. Teaching methods must suit the learning styles of those learning. One can present multi-media teaching vehicles, such as interactive CD-ROMs, videos and workbooks so as to insure that learning to operate the digital printers can perform effectively. Redundant written, visual and hands on instruction will enable each learner to choose the learning style which works for him or her.

Equipment manufactures must maintain a dialogue with their ink manufacturers which in turn must communicate with their suppliers and users. Software developers must talk to the developers that their software will control. Often a supplier will know of a solution to a problem with which its customer is struggling. Customers will often have solutions to problems. But customers always have valuable perspectives. If all the parts are to work together, then all the partners must.

Chemistry—Developers interviewed for this report often cited ink chemistry as the greatest current challenge for ink jet development. Ink formulators are beginning to tackle the issues related to direct print ink jet inks. jumping the hurdles of low viscosity ink creation. Toxot has developed two textile inks for use with its multilevel continuous ink jet. One, which Embleme has used to print T-shirts and fabric for the past two years, is a water-soluble monomer free UV curable ink. Despite fears that UV inks on textile might cause skin irritation, Embleme and Toxot report no incidents of such. Embleme has printed and sold thousands of shirts with this ink. The other Toxot ink is a thermally curable water-soluble pigment loaded ink which has excellent wash fastness and crock resistance based on ISO test.

Armor of Nantes, France is partnering with Embleme to develop alcohol based textile inks for use with the XAAR based piezo ink jet systems which Embleme is developing.

Airbrush digital printer manufacturers Belcam for the Michelangelo and Raffaello, and New Image use inks for fabric banner printing which carry multi-year outdoor durability and weatherability guarantees.

DIS supplies a pigmented thermal ink jet textile ink for use with its printers. Canon also offers a wide range of dyes color sets for its "Wonderprint" printer. Canon's ink systems are fiber specific. Since printing different fabrics would involve considerable time flushing ink from the system, reloading and testing, Canon suggests devoting one almost $1 million machine per fiber type you might print. At production speed of 1 running meter per minute and considerable head maintenance, we can expect other technologies to capture more of the market than this device. Thermal drop on demand inks also suffer from the print device boiling them in order to print.

Sawgrass has patented an ink jet printable sublimation dye transfer system. Other companies have developed similar inks.

Fusion Systems of Gaithersburg, MD has patented an Eximer UV curing system that concentrates its emissions in one UV wavelength. The bulb uses the same amount of electricity but generate almost ten times the effective energy, because none of the radiation is in wavelengths that are extraneous to curing. Ink formulators can now use one wavelength specific photoinitiator that matches the UV bulb's specific wavelength output, instead of the current practice for UV curable inks where formulators employ multiple photointitators to stimulate curing at different levels of ink depth. The concentration of energy in one wavelength permits significant reduction in the type, amount and expense of photoinitiators, the most expensive ingredients in UV ink. This price reduction may favor consideration of UV inks for digital textile printing. The new energy curing levels will permit curing of pigment loaded and opaque inks. This new curing technology faces two stumbling blocks to its adoption for textile printing. The increased energy levels could have an adverse affect upon ink chroma, and the yet to be announce, but certainly high, cost of the eximer curing system. Fusion project launching the eximer system in the Summer of 1996.

Printing on dark colored garments constitutes about 40% of T-shirt printing. Some printers specialize in dark garment printings. For one strategy to print dark garments digitally, ink manufacturers are trying to develop digital inks with sufficient opacity to cover all fabrics and dye migration blocking capacity for polyester containing fabrics. For another strategy to work, ink developers will have to create a digital discharge system. Since current discharge chemistry contains urea formaldehyde which will corrode most ink jet heads, developers must design print heads that will resist corrosion. Tektronix of Washington uses stainless steel heads that would withstand this type of corrosion. The urea formaldehyde can also produce a corrosive effect on operators and other process equipment, such as the interiors of thermal curing units and vent pipes. But one can obviate these problems with urea formaldehyde resistant coatings and effective ventilation. Currently, many brands of T-shirts when heated to the temperatures necessary to cure plastisol inks will off-gas formaldehyde in amounts comparable to what discharge inks would emit without excessive corrosive results.

Conclusions

The technical and economic hurdles to digital printing are formidable without being insurmountable. Industry can overcome them with time, money and commitment. Digital technologies exist which industry can assemble to print textiles as bolt fabric, cut pieces or garments, addressing most of the challenges described. The economic forces which will drive the move to digital printing are already demanding inventory reduction and quick response delivery which digital textile printing can help realize.

In the United States, consumers spend $246 billion dollars on retail textile sales, $172 billion of which are for apparel. Approximately half of that is printed. About 21 billion meters of fabric were printed worldwide in 1995. Textile printers and manufacturers will continue to compete to have a large slice of this pie. As retailers move to reduce warehousing and inventory carrying costs, they will increasingly demand just in time delivery of textile and apparel items. Apparel retailers have begun to increase the number of yearly fashion seasons from three to six. They are demanding more fashion items, products that are offered for only one fashion season. Continual change characterizes the trends in retail purchasing and sales. Manufacturers and textile printers will adjust their processes to respond to these demands in a cost effective manner. Digitally controlled printing and processing offer the flexibility necessary to satisfy customer and retailer demands. These technologies will also permit retailers and customers to expand choices and to actually design garments and their decoration. We will see the development of new channels for textile distribution. Customers will be able to communicate directly with the manufacturing facility which is creating the garment that they have selected and designed. Companies, like Levi Strauss, have lead the way in monitoring retail sales digitally to determine resupply priorities. This San Francisco manufacturer offers its customers the option of tailoring the fit of the jeans they order.

Demand for textiles and apparel is likely to remain steady with no significant source of new growth appearing in the US, European and Japanese retail markets. As consumers in developing countries acquire improved purchasing power, we will see growth in those markets. As the market continues to move toward customization, personalization, inventory reduction, textile manufacturers will embrace digital processing and imaging technologies to stay competitive. We will likely see more integration of the manufacturing processes. Modular manufacturing and sewing units with print-cut sew capacity will begin to replace the profound fragmentation which has characterized the textile industry, particularly the apparel industry in the US. We may even see the automated operations of spinning, treatment, and weaving integrate with automated printing and cutting, while the more labor intensive and less readily automated sewing functions are out-sourced, and exported to lower labor cost areas when time constraints will permit. US apparel manufacturers are already proceeding down this path. The incipient growth of modular sewing and projected growth of modular manufacturing will respond to the new driving retail and design forces demanding quick response to customer choices and virtual elimination of warehoused inventory. Digital color printing fits as part of this picture and as a complement to conventional textile printing methods such as screen printing.

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