Print and Archival Topics: Laser Digital Color
Robert Anderson

This review highlights what is known about the archival properties of laser digital color prints and compares it with thermal ink jet. An additional objective is to compare color laser digital with ink jet image quality, for the high quality printing end user. This latter objective is important since it is the improvement in image quality that has brought laser digital color printing into the realm of art and photo applications.

Key messages:

• Laser Digital Color printing (LDC) technology has matured to a point where quality levels can satisfy many demanding customer applications, including the printing of professional photographic images. It can now be considered a serious alternative to both traditional offset color printing and high quality ink jet. While ink jet prints are sometimes seen to be more saturated and "vibrant" by some observers for some images, LDC technology is narrowing this.

• A basic review of how LDC technology works is given to help users appreciate its strengths and weaknesses, particularly in comparison to thermal ink jet printing.

• LDC has additional operating characteristics that can sometimes make it the preferred alternative over these other technologies. In particular, speed, cost/page, and ubiquitous two-sided printing are three factors that make LDC more suitable for producing multiple copies of prints, books and catalogs than the use of ink jet.

• Professional ink jet printers (e.g., Epson 9800) on the other hand, can accommodate much larger sheet sizes (up to 44 inches wide by several feet in length). This capability is particularly advantageous in the production of larger fine art prints.

• Given the ability of LDC to compete for the production of photographic books and smaller fine art prints (generally 14"x22" or less), it is necessary to understand the archival nature of this output form.

• Two primary factors of archivability pertain to stability of the image itself, and the stability of the paper on which the image is placed. Because the colorants in the LDC printing process are typically pigment-based, they will have similar aging characteristics to today's best pigment-based ink jet inks. Most LDC systems can also print reliably on a wide variety of paper substrates, including those developed to minimize yellowing.

Therefore if one takes care to print on "archival" papers, one can presume that color prints by LDC systems will enjoy a long life expectancy, comparable to "best of breed" ink jet output. Under the best conditions it has been shown that both ink jet and laser digital color can produce images that are stable from 10's of years to 100 years or more.

Introduction

High quality graphic arts, fine arts and photo printing from color digital sources have been dominated by ink jet technology. However, this is changing with the newest manifestations of laser digital color technologies. It is generally recognized that laser digital color printing has made great strides in office and light production applications. It is less well appreciated that it is also a serious competitor in the highest quality applications such as photo printing, graphic arts, high end lithography and even fine arts printing. No single breakthrough is responsible for this, but instead a steady stream of quality and reliability improvements during the last decade has made this possible.

Principle among these has been the progress in print quality driven by increased laser resolution, finer toner particle size, improved toner particle size and shape control, and improvements in the overall electronic and mechanical stability. Furthermore, all of this can be achieved on cut sheet papers of various sizes, weights and surface finishes. The resulting print quality improvement has led to the up-market movement of these technologies into high quality applications.

Some of the current products that are being used in these higher quality color laser digital applications include Xerox's Docucolor series: iGen3, 6060, 7000 and 8080 families; Nexpress's 2100 family, and HP's Indigo family. These represent the higher end versions, in terms of speed, quality and cost, of a growing range of offerings. These and other vendors also offer intermediate products in size, cost and speed that are also meeting high print quality levels.

For the customer, these technologies enable new opportunities for producing high impact color documents at decreasing cost. For equipment vendors, as well as commercial printers, it represents major opportunities for new markets. Given the growing volume of the output of all this activity, image quality and longevity are obviously of enormous importance. Equipment vendors usually stress visual aspects of quality and to some extent physical attributes such as document flatness (extent of curl). However, archival properties are generally not discussed broadly for these technologies. That is not to say that this area is neglected or even deficient, but equipment vendors that are primarily in business applications do not give print longevity and durability significant voice. So, particularly for customers in the higher quality applications the question of archival print stability is a pertinent question for cut sheet laser digital color printing.

Defining laser digital color

An important starting point is to define laser digital color printing and to show its differences to color ink jet printing. In this discussion two laser digital color technologies are encompassed: dry toner xerography and liquid ink printing (as practiced by Hewlett Packard's Indigo products). Liquid ink printing in this discussion should not be confused with thermal ink jet printing which also utilizes a liquid ink. Laser digital color is the technology set that uses a laser and either the xerographic or more generally the electrophotographic processes to produce the final prints. The terms "electrophotographic" and "xerographic" essentially describe the same process that will be outlined in the following. Electrophotographic is the more general term and dry powder development invented its own name – xerography.

In laser digital color printing the laser converts the digital bitmap of the image into a charge pattern – the latent image - that is developed by dry powder (typically known as toner or dry ink) in the xerographic process. In liquid ink printing a liquid ink develops the latent image. The developed images are eventually transferred and fixed to paper or other suitable media substrate.

In either process the liquid ink or dry toner is carried to the electrostatic latent image by what is known as a developer. In liquid ink the developer is the liquid, often a low boiling point hydrocarbon, mixed with colored particulate inks. The liquid developer is carried to the paper or final image substrate along with the colored toner particles. The liquid is blotted away and/or evaporated from the image substrate, typically paper. In dry xerographic systems the developer consists of two types of particles: carrier particles (typically iron based particles) and the toner particles. The carrier particles are usually much larger than the toner particles. The toner particles are electrostatically attracted to the carrier particles and taken together comprise the developer. The developer is mechanically and/or magnetically (remember the iron in the carrier particles) presented to the latent image which can electrostatically remove the toner particles from the developer to finally develop the latent image. The carrier particles are swept from the latent image by mechanical or magnetic forces.

Color is accomplished by combining cyan, magenta, yellow and black (CMYK) individual layers to the media substrate before the fixing operation. These steps are implemented in several different configurations by the various vendors, but most of the intervening steps and elements are variations on the xerographic or electrophotographic process, especially in regards to producing and combining the color separations. Toner or ink particles, either dry or in a liquid vehicle, are deposited on the latent image location where the laser is either in the on or off state forming what is known as a "pixel" or picture element. Adjacent pixels are grouped together in various patterns to form the halftone dots used to form the image. The resolution and halftone dot size is achieved by the optics of the laser systems. Many current systems achieve 2400 dpi pixel resolutions.

The dry toners are typically pigment colorants dispersed into polymer. These particles are formed either by mechanical fracturing and size sorting or by a newer process of chemical particle growth methods. These chemical particle preparation technologies grow the particles in a bath so that the ingredients, including colorants, and particle size are controlled by the chemistry and the outcome is a much more controlled particle in shape, size and composition than the older melt/mechanical fracturing technology. Particle sizes today are in 5 to 9 micrometer range.

The ink in liquid ink digital printing consists of 1 to 3 micrometer particles of polymer with pigment colorant dispersed within. The ink particles are carried to the image substrate by a liquid vehicle as described earlier.

Ink jet by comparison uses a process where the digital bit map (the image structure in the electronic file) is converted to imaged color dots – pixels - by electronically firing individual ink jets to produce color ink drops that mark directly onto the image media. The color drops form the color separation halftones corresponding to the original image bitmap. The image dries on the image media to form the final print. The image resolution is basically driven by the ink jet drop size or volume and the best resolutions currently are in the 2400 dpi range.

Comparing laser and ink jet printing

So what are the advantages and disadvantages of laser digital color vs. ink jet? At the most obvious level the primary metrics are speed, sheet size and cost. Laser digital color is currently producing high quality prints at over 100 letter sized sheets per minute, far faster than the best ink jet. Ink jet on the other hand can print virtually any size up to and including large posters. Ink jet systems are typically much less costly to purchase than the more complex laser digital color systems. However, the running costs for ink jet, that largely determine the page cost, are as much as 10X that for laser digital systems. At other levels, comparisons are less sharply drawn. Ink jet until recently had been dominant in photo print applications, but now laser digital is solidly in that arena. Indeed, laser digital color now fully rivals ink jet in quality. Laser digital printing can inherently print to a larger variety of conventional paper stocks, but ink jet manufacturers have been quicker to develop the types of papers often desired by fine arts print makers and customers. The simpler ink jet systems are more reliable. Duplex (i.e. two sided) printing is common in laser digital, but relatively rare in ink jet. The list goes on with the end user needing to determine the best overall fit to their needs.

Archival discussion

A large body of literature on archival stability exists on digital printing with ink jet1, but much less so for laser digital printing. What are the differences, what are the common issues? The discussion around archival stability divides into several key topics. At the most general level, archival stability for both ink jet and laser digital focuses on two topics: paper stability and color stability.

Paper stability

The primary stability issue for paper is yellowing with age or exposure to high intensity illumination. Paper stability can be more complex for ink jet since the ink-paper interaction for the highest quality applications requires special paper treatments and additives. These in turn can add complexity to paper stability since yellowing is basically chemical or photochemical oxidation of the paper fibers or any of the additives. In general, the best quality papers for ink jet have been engineered for stability against aging, but it is recommended to check with the manufacturer for specifications on stability. Papers for xerographic systems tend to be more standard papers with no need for optimization for toner interactions. This means that the best papers for general archival use can often be used for laser digital color printing, but as with ink jet printing it is wise to check with the paper manufacturer for specifics. The best papers for either ink jet or color laser printing should show specifications that include acid free, lignin free, optical brightening agent free and 100% cotton2. Papers with these characteristics can maintain their color for 100 years and longer3.

Color stability

Color stability fundamentally revolves around whether pigment or dye based colorants are used. Pigment based systems are known to have excellent stability and are used in extreme exposure applications such as auto paints. Pigments are inherently more chemically stable than dyes, but dyes can give more vivid or brighter colors – a larger color gamut. Pigment colorants are commonly used in color laser digital systems, but are somewhat less common in ink jet, except for high quality applications. The difficulty in ink jet is due to the fact that pigment colorants are insoluble and require a stable dispersion in the fluid ink systems. Other difficulties for pigments in ink jet printing are particle clogging of the ink jet nozzles, since pigments themselves are small particles. All of this is manageable, but typically at higher ink and printer costs. Color degradation can be in either hue or saturation, but typically affects saturation initially. In severe cases hue is impacted, and this often appears as a general loss of "vibrancy" or appearance of "muddiness". Under the best conditions it has been shown that both ink jet[4] and laser digital color[5] can produce images that are stable from 10's of years to 100 years or more. Sometimes pigment systems in both ink jet and laser digital are augmented by addition of dyes to enhance color gamut. This is most often done in the magenta colorants. The trade-off is possible loss of color archival stability due to color fading of the added dye.

Xerographic laser digital systems typically incorporate pigment colorants in the dry toner. The dry toner particles are typically formed by dispersing the colorant pigment(s) into a polymer (plastic) matrix in a hot melt state followed by solidification and mechanical fractionation to form the actual particles. The pigment dispersions in these systems are quite stable without any special effort, due to the viscosity in the melt mix and the solid form of the final particles. Black coloration is usually accomplished with various forms of carbon black that behaves much like a pigment and not a dye. As discussed earlier, after image deposition onto the substrate the toner particles are melt fixed or fused. The resultant image layer consists of the colorants still dispersed in the polymer that is intermingled into and on the paper fibers.

The HP Indigo electrophotographic system is an example of digital liquid ink technology discussed earlier, but the image forming process is essentially the same as in xerography. The toner particles are significantly smaller than the corresponding dry toner particles in xerographic systems, but they are formed in a similar process. Like dry toner xerographic systems, the particles in the Indigo system are typically pigmented and have excellent color stability. However, the particles in the Indigo system are carried to the image substrate dispersed in a liquid carrier material that is subsequently removed. This system produces a thinner image layer on the paper than xerographic systems due to the smaller size of the toner particles. Unlike xerographic toner systems the image layer in the Indigo system is characterized by the toner particles mingling and attaching to the paper fibers forming a thin layer. This compares to forming a thick layer attached to and on the surface of the paper fibers as is characteristic of dry xerographic printing. To reiterate, both the xerographic and electrophotographic (HP Indigo) systems have excellent color stability primarily due to their use of pigment colorants.

Other archival considerations

Other archival considerations include scratch resistance and image retransfer resistance. Scratch resistance focuses on resistance to mechanical abrasion. Ink jet systems operate by having the colorants attach to and intermingle with the paper fibers. Scratch resistance in this case typically approaches the surface mechanical integrity of the paper substrate and is very good. Laser digital systems have more of the image as a pigmented polymer layer on top of the paper fibers, although at the paper interface the polymer does flow into the fibers during the fixing/fusing process. However, the top of the image layer has scratch resistance determined by mechanical properties of the polymer. Generally speaking, but depending on the polymer used in the toner system, these layers are very durable and can approach the integrity of typical paper fibers. As discussed above, the HP Indigo system has a thinner image layer, somewhere between dry toner and ink jet, and the result is somewhat more susceptible to scratching than either ink jet or the dry xerographic systems. Indigo has partially solved this with the introduction of special papers, thereby somewhat limiting customer paper use options.

Colorant image retransfer is the result of a portion of the image transferring off the image onto another surface such as the back side of a covering sheet. Typically this is initiated by elevated temperatures such as present in shipping and by pressures that would result from large stacks of sheets or books. This type of image loss is more common with dry xerographic systems since it involves the colorant loaded polymer layer that forms the image. This is somewhat similar to the fixing/fusing process used to attach the initial layer of particles to the paper, except that the pressures and temperatures in retransfer are typically lower and only a limited transfer occurs. Again, manufacturers have worked to minimize this effect by careful design of the toner polymers.

So, it is seen that the archival characteristics of the various technologies can be comparable, with trade-offs and careful selections required in all technologies. Generally, ink jet systems with pigmented inks perform very well in terms of archival issues. Likewise, xerographic systems which are primarily pigment based perform well provided the toner polymers are designed for archival durability against a variety of stresses. Papers with good archival characteristics are available for both technologies.

Image quality discussion

Image quality usually brings to mind pixel size. Pixel size does indeed play a large role in image quality, but there are many other factors that play an important role. Usually these are highlighted in terms of the resultant image defects and the following discussion of image quality will be in those terms. Image quality defects can be a significant issue in laser digital color systems as well as ink jet systems. In both technologies, mechanical stability and system complexity usually are the cause. Often these defects are most noticeable in low density or mid-tone areas and least noticeable in full density or saturated areas of the image. Also, high frequency image content (i.e. busy image areas) is the most forgiving for defects. Typically streaks and bands are the most noticeable defects. Others are spots, deletions, and uniformity variations.

Laser spot size in laser color digital systems is a key enabler for high image quality. As with much of the other aspects of the system, spot size has continuously improved over time and is now at the 2400 dpi (dots per inch) level in the best systems. Spot size enables higher halftone screen frequencies and screen types and it impacts tone reproduction response (bitmap image density vs. output density). Of course to achieve these enabling spot sizes more than the laser is involved. The laser imager, due to the unique properties of laser light, can easily achieve small optical focus sizes, but the remainder of these complex systems must be able to sustain these sizes. This includes the all of the image carrying subsystems including toner size. As a consequence, toner size has shrunk to 5 – 7 micrometers in dry toner systems and 1 – 3 micrometers in liquid systems such as the HP-Indigo. Interestingly, ink jet systems have also shown the ability to achieve 2400 dpi image dot sizes by using ultra small drop volumes.

Color defects usually derive from system CMYK color drifting as well as halftone issues from mis-alignments or mis-registration. These occur through component or material aging, break-in phenomena, temperature or humidity shifts, dirt accumulation in/on components, and component failures. Color mapping (maintaining consistent color from input to output) issues is not usually regarded as a defect, but are more related to intrinsic system color gamut, tone reproduction response and halftone screen issues. Most graphics professionals and commercial printers incorporate a color managed workflow into their processes in order to address color mapping.

Another class of defect is related to integration of the image with the media. The fusing/fixing process in laser digital technologies can cause objectionable gloss variations or gloss level, and even media unevenness such as cockles or ripples. Objectionable curl and even media shrinkage can also occur. Ink jet has similar issues with the interaction of the fluid carrier material with the paper that can cause cockles and paper unevenness.

An important innovation that has been evolving in these technologies is the use of sensors and feedback controls. These are now monitoring on-line image quality as well as color and providing system level feedback for defect remediation or service calls.

Defect minimization in all technologies is usually accomplished with extremely careful engineering – tight tolerances, high quality parts, precision gears, stepper motors, dirt management, etc. Also, close attention is given to system simplification wherever possible. As has been mentioned, many of these systems have evolved through several major technology generations with all the expected improvements. Continuous improvement through multiple generations is one of the key reasons that color laser digital systems are now capable of competing at the highest quality levels.

Summary

Digital color laser printing has been discussed as a viable alternative to ink jet for high quality printing applications. A basic description of digital color printing and comparisons between the two technologies has been given in the context of archivability and image quality. The objective of this has been to provide useful understanding to the customer about the competing printing methods as they make important choices between these two printing methods.

References

1. http://www.wilhelm-research.com
2. Papers that meet the ANSI, ASTM or JCP standards for paper permanence. See for example http://palimpsest.stanford.edu/byorg/abbey/ap/ap03/ap03-4/ap03-416.html; or http://www.conservationresources.com/Main/S%20CATALOG/Specifications%20for%20Archival%20Papers.htm; or http://www.crane.com/museo/paperspecs.aspx; or http://www.crane.com/museo/museo2.aspx
3. Paper longevity, see http://www.mohawkpaper.com/pdfs/9.%20Paper_Permanence.pdf; or http://lib.store.yahoo.net/lib/skyimage/UltraSmooth.pdf
4. Ink jet longevity, see http://www.wilhelm-research.com/hardcopy/hardcopy.html; or http://www.wilhelm-research.com/ist/ist_3_04_preview.html
5. Laser Digital Color longevity, see pg. 37 of http://www.wilhelm-research.com/pdf/HW_Book_03_of_20_HiRes_v1a.pdf#search=%22light%20fading%20stability%20of%20displayed%20color%20prints%22; or pg. 8 of http://www.wilhelm-research.com/ist/WIR_ISTpaper_1995_05_HW.pdf#search=%22a%20survey%20of%20light%20fading%20stability%20of%20digital%22

About the author

Robert Anderson received a BS in chemistry from Drexel Institute of Technology (now Drexel University) in 1969. He also received a Ph.D. in Chemistry from the University of Pennsylvania in 1976. Recently retired from Xerox Corp. with 30 years of experience, his main work was in development of color toner materials and the xerographic process. He is the author of over 25 scientific publications in photochemistry and photochemical energy transfer and holds eight US patents.