ELECTROCOAGULATION : A NOVEL CONTONE HIGH-SPEED DYNAMIC DIGITAL PRINTING TECHNOLOGY

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Abstract: Elcography is a novel printing system based on the electrocoagulation of an electrolytically sensitized polymeric ink. By applying very short electric pulses to a colloidal ink solution sandwiched between a cathodic electrode array and a passivated rotating electrode, the ink adheres firmly to the positive electrode. The ink is then instantly transferable, after removal of surplus ink, onto plain paper.
By modulating the electronic pulse time for each electrode, the volume of each coagulated dot is controlled in very fine increments, allowing true continuous-tone imaging. Because of its extremely fast writing process speed with parallel addressing (4 microseconds/dot), its low supplies cost, and its photographic quality (200 pixels per inch, 256 grey levels per pixel), Elcography has great enabling potential to convert a very wide scope of applications to digital printing such as newspaper publishing, commercial printing and photofinishing. Current printing speed is currently at 1 meter per second with potential speed that could go up to 3 meters per second. This paper will describe the fundamental characteristics of electrocoagulation printing as well as its decisive advantages over conventional printing processes.

Background of invention

Before being an invention Elcography® was a desire and an idea. The desire was to obtain photographic quality on plain paper rather than the photo-sensitive silver halide photographic paper. Lithographic printing was not suited for the individual printing of photographic negatives and it had some of the same environmental problems than photo-chemistry.
The idea of the invention was born in an indirect fashion in 1971 from the experiments of Adrien Castegnier, an industrialist in the photo-finishing industry. From his experience in photo-processing, he knew how complex and costly silver-halide photo printing could get in a high production environment.
There had to be other printing techniques that would offer the same image quality than photo–chemical photography without its drawbacks. Because of these process limitations, he concentrated on the potential of electrolytic processes.

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In 1971, he was thus pursuing an earlier idea he had when working as an apprentice in a rotogravure plant in Paris. The original idea was to build a sort of gravure cell in a gelatin substance with gas bubbles generated by electrolytic reaction between two electrodes. The depth of the cell would have to vary in correspondence to the desired density of the point. If the cavities were then filled with ink, the image could be printed on regular paper. (U.S. Patent #3,752,746). By varying the time of electrolysis the bubbles would grow at different rates. as can be seen in Figure 1(a). These bubbles form cavities once the gelatin is solidified by evaporating its water content. The gelatin master with cavities of different depths was like a gravure cylinder. The shallow cavities transfer less ink to paper than a deeper cell. Although clever, this scheme was not fully satisfactory. The bubbles were unstable and a deposit of gelatin was always sticking to the positive electrode. After many trials to avoid this deposit he observed that this parasitic layer was of varying thickness as schematized in Figure 1(b).

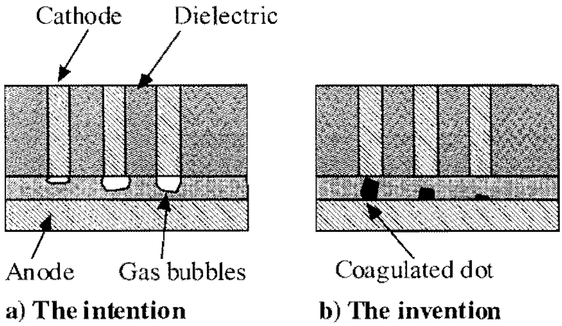

Figure 1 : Electrocoagulation discovery

Why build a gravure cell to obtain dots of varied densities when the same result is already there with the variable thickness layer on the positive electrode? He then applied a color dye to the gelatin layer and transfer it to paper to obtain the first dot ever printed by electrocoagulation. From this moment on, the invention and its idea was born. All it took to make this into a full blown technology was a little care and feeding.

Technology milestones

In 1974, Electrocoagulation was tested on the bench at high voltage and different printing engine designs were explored, such as a moving single electrode print-head, as well as an array of fixed electrode in front of a revolving cylinder, and a printing engine with fixed negative and positive electrodes in the same plane.

In 1975, Adrien Castegnier obtained the first patent describing the use of the Electrocoagulation process for printing purposes (USP #3,892,645). Still, a few disadvantages of the process had to be cleared before building prototypes.

In 1978, the first image reproduction was obtained with a mono-electrode on a metal cylinder. The first image transfer was realized on a gelatin surface. There was also unwanted accumulation of gases at the interface of the negative electrodes. Corrosion of both types of electrodes made the process unreliable for production printing. Image quality could not be uniform in the same image, and from print to print mostly because gelatin and albumin were of inconstant quality,

In 1981, Adrien R. Castegnier founded Elcorsy to explore possible solutions to these technical problems.

The concept practicality of variable thickness half-toning was to be verified by testing with the development of a breadboard desktop printer. In 1983, this static printing prototype was completed, the image coagulated on a flat sheet of metal covered with gelatin and was then transferred by hydrophilic transfer on gelatin - coated paper. Images of photographic appearance were realized with success.

The next prototype to be developed was to be a poster printer printing four impressions per minute based on a dynamic printing design with a metal plate wrapped around a cast iron cylinder.

In 1984, fundamental findings about suitable colloids were tested. Instead of using gelatin or other natural colloids, superior performance could be obtained with synthetic polymers. Uniformity in their molecular weight made the process more uniform from print to print, with less gaseous side-effects on the negative electrodes.

In view of these developments, described in USP #4,555,320, a new program was set up with the goal of building high-speed color prototypes.

The first prototype (USP #4,661,222) was built around a metallic belt passing through five separate image developing stations. The first station was coagulating the transparent colloid, the second step wiped off the non-coagulated colloid. The coagulated image was then colored by absorption of a dye, a softening agent had then to be applied so that the transfer on paper could take place (USP #4,764,264). There was also a cleaning station to erase any remaining colloid.
Good density levels were obtained, but the imaging belt was too fragile for long-term use. Also, the multiple printing steps were limiting speed to 20 impressions per minute even though laboratory tests showed much higher potential printing speeds.

In 1985, a new prototype generation built around an horizontal cylindrical positive electrode with a fixed array of negative electrodes was designed to take advantage of the integration of ink pigments in the colloid solution. This approach made possible continuous Electrocoagulation printing, eliminating the time bottleneck caused by the coloring station.

In 1986, Elcorsy developed a chemical technique (USP #4,680,097 and USP#4,786,385) that eliminated corrosion effects on the continuous-cycle prototypes. By coating the positive electrode with an olefin substance, the gas

bubbles trapped between the electrodes are consumed by reaction with the unsaturated oil.
A side benefit of the oil coating was the easier transfer of the coagulated dots from the printing cylinder to paper surfaces. The coagulated colloid didn't need to be softened to enable transfer of the image on paper.
The first impressions using this technique were done in August 1986. Constant quality Electrocoagulation was obtained on the imaging cylinder at speeds of 30 cm per second.
However, the coagulated image was not entirely transferred on paper, resulting in density variation from print to print. When transfer was successful, the image quality was comparable to good quality offset prints, even if resolution was only 100 line pairs per inch.

In 1987, the cylindrical prototype was entirely redesigned to optimize Elcography® printing parameters (USP #4,895,629). The coagulation cylinder was set vertically to obtain uniform injection of colloid and very precise oil coating by simple gravity.
This vertical design also gave more configuration options for the polychrome prototype. The four coagulation stations could be arranged around a central transfer cylinder (planetary design), or there could be four independent coagulation stations with four transfer cylinders arranged in sequential order.

In 1988, integral transfer of the coagulated image on paper was realized by using a wetting agent. The sequential printer design was chosen over a planetary design tried earlier. The high pressure applied during printing wore down the central rubber cylinder. This caused variations in applied pressure and in the contact surface of the coagulated image with paper, resulting in uneven image transfer.

In 1989, the image resolution was raised from 100 to 200 line pairs per inch. Photographic quality was near, but imperfections were still present because of small dirt particles and imperfect transfer of the coagulated image on certain types of papers.

In 1991, with testing of three color stations printing in-line the first trichromatic elcographic prints were achieved. Even with high background densities, image line structures and imperfect registration, the image quality was encouraging.

In 1992, functions such as real-time Unsharp masking, on-the-fly color correction and image format changes were implemented with success in the electronic control system.

In 1993, a special interface with the Windows Platform was successfully developed allowing image scanning and editing plus text composition with off-the-shelf software. The interface was not in real-time but it could transfer an image in less than 2 minutes to the printer.

Laboratory tests using a marking agent have confirmed the hypothesis that the initiating factor of Electrocoagulation are metallic ions migration from the anode into the ink when current is activated. These metallic ions are known for their ability to coagulate very rapidly a polymeric network in colloid suspension.

In 1994, a new improved oiling system was developed that insures a thinner and more uniform oil coating on the imaging cylinder. USP# 5,449,392 and USP # 5,472,744 were granted for this system.

In 1995, extensive printing tests in four colors were done on newsprint paper with excellent results. Color register is relatively easy to maintain and text and color image quality is equivalent to offset .

In 1996, a 12 inches wide press printing at 1 meter per second was developed in Montreal while a 24 inches wide press was built in Japan by Toyo Ink in collaboration with Elcorsy. In June 1996, Elcorsy and Toyo Ink revealed the Elcography® technology at NEXPO in Las Vegas.

Electrocoagulation mechanisms

Electrocoagulation is based on an electrochemical reaction that affects an electrolytically sensitized polymeric ink. By applying very short electric pulses to the colloidal ink solution sandwiched between a cathodic electrode array and a passivated rotating electrode, the ink adheres firmly to the positive electrode or imaging cylinder. The ink is then instantly transferable, after removal of surplus ink, onto plain paper.

The ink is composed of a type of polymer often used in waste-water treatment. This linear polymer is in suspension in water and forms a network which has a tendency to fold onto itself in the presence of metallic ions. The solvent is water mixed with electrolytic salts to render the ink conductive.

When current is activated between the cathode and the anode there are the following electrolytic cell effects :

1. The first step is to be sure that the printing drum surface is passivated
2. We then activate the cathodes where we want to print a dot. All subsequent chemical reactions are automatic results of these two controlled actions.
3. Chloride ions generated by the electrolysis are breaking the passivation layer of the imaging cylinder.
4. This brings the fourth reaction where metallic ions are coming out of the cylinder into the ink.
5. The metallic ions are grabbing many polymer strands in the ink and are binding the polymer strands together and grafting them to the anode surface. This is what is called coagulation.
6. The binded polymer strands are then collapsing on the anode so that they are anchored very strongly on the printing cylinder. The water content of the coagulated dot is not the same than the water content of the ambient ink solution. The reaction stops immediately when the current is turned off. The amount of coagulated ink can thus be modulated by variable time length of electric pulses. When observed with an electronic microscope, the coagulated dots on the imaging cylinder are three-dimensional dots as we can see on Figure 2.

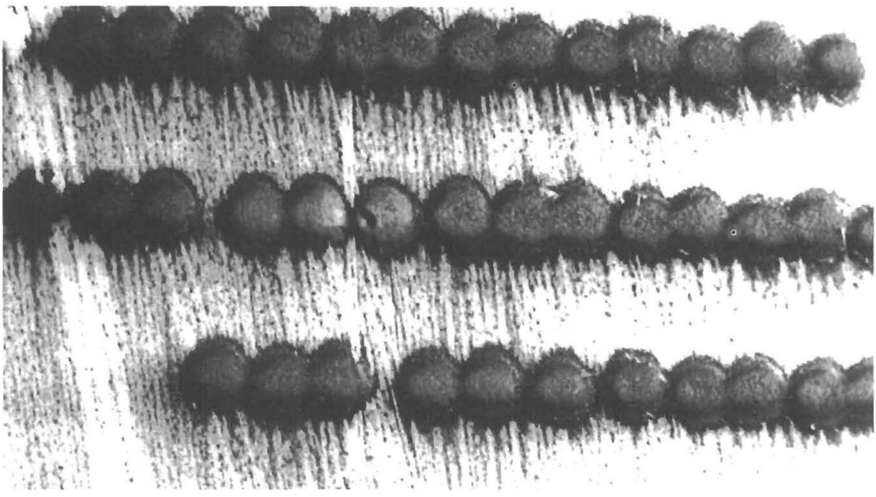

Figure 2: coagulated dots on anodic imaging cylinder after removal of excess ink

Printing apparatus

To control the electrochemical reactions described above, the Elcography technology evolved to the current design comprising the following components as shown in figure:

1. Conditioner
This station uses rollers and brushes to apply a thin layer of oil is applied prior to the ink injection. This layer serves as a sacrificial layer for the image transfer on paper. It also serves to capture gases generated by the electrolysis of water.

2. Inker
The ink is injected by a free-flow device and is carried by the rotation of the cylinder into the gap between the printhead and the imaging cylinder. The operator has no mechanical adjustment other than making sure that the flow is sufficient to fill the gap. Dot Density is controlled solely by the electric pulses duration sent by the print-head.

3. Printhead
The printhead receives the data from the computer and converts it in corresponding electrical pulse widths. It is formed of a cylindrical body where micro-electrodes are embedded into an insulating material. There are 2048 electrodes over a $10^{1/4}$ inches length. The data coming from the computer memory is entering via a socket on the printhead axle and multiplexed to the driver circuits located inside the printhead. Each driver circuit controls multiple addressing electrodes. These electrodes are conducting the electric pulse through the conductive ink. The gap between printhead is critical and must be maintained between 50 and 75 microns. Actually, the gap is set manually with a micrometer at the beginning of each print session. Future versions will provide for automatic

gap control. This circular print-head design was chosen because of the solidity of its frame to insure a uniform gap all along the imaging width. The printhead can also swivel so it can be cleaned with a simple cloth without dismounting it. One other interesting feature of electrocoagulation writing is that it is a fixed addressing system. The positioning of dots is thus very precise in the lateral direction and there is no cross-talk between electrodes. The coagulated dot on the anode occurs always on the exact opposite side of the cathode location. This means that once the print-head is manufactured, there is no ballistic uncertainties in dot positioning that could bring random micro-banding.
In the web direction, the dot positioning is also very precise and can be controlled by print-head circuits to adjust for color misregistration.

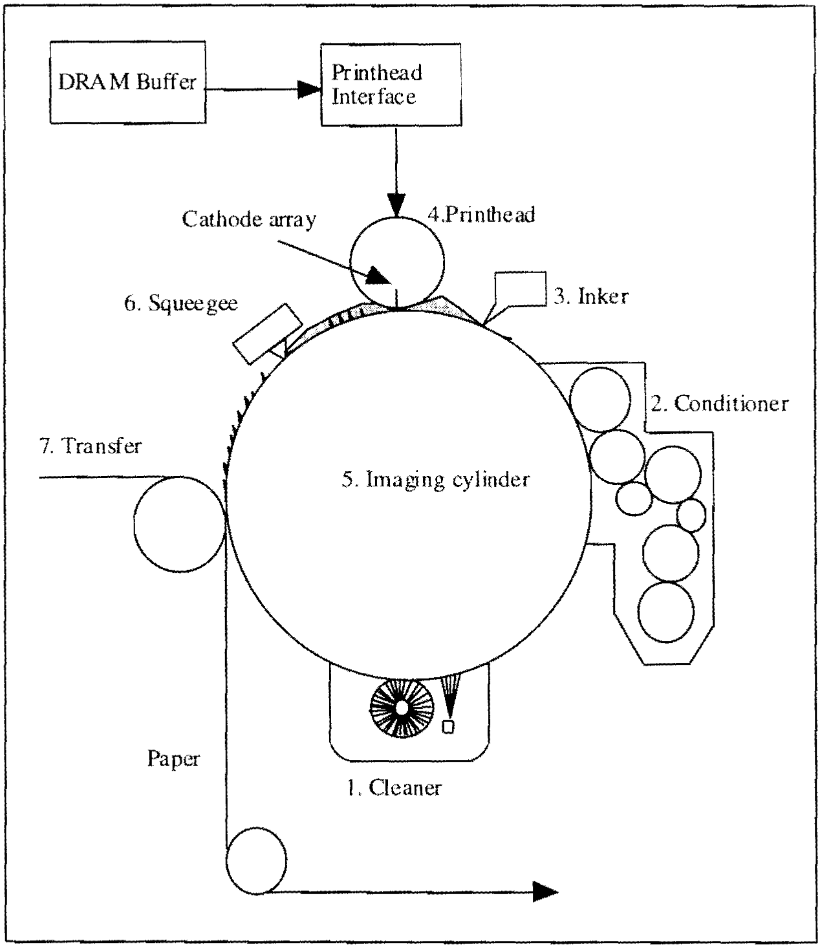

Figure 3: Elcography® printing cycle

4. Imaging cylinder

When the cathodes are activated, metallic ions from the imaging cylinder are released in the ink solution. These ions form a very efficient bridge between the polymer strands in suspension in the ink and the imaging cylinder substrate. The polymer strands then collapse against the imaging cylinder. The electrocoagulation imaging cylinder has the particularity of bringing the elements necessary to the imaging reaction as well as being the carrier of the image to the revealing and transfer stations. The metallic ions, are depleted from the cylinder in minute quantities and is available for the next printing cycles at a constant rate. The imaging properties of the electrocoagulation cylinder are not decaying with the number of impressions. This is a fundamental difference with photo-conductive imaging substrates used in Electrophotography which show image fatigue at relatively low printing volumes.

4. Squeegee

After imaging, the printed dots on the imaging cylinder must be separated from the surrounding ink. Since the imaged dots are more cohesive than the ambient ink and because they are adhering to the imaging cylinder, a simple rubber blade can separate the coagulated dots from the non-imaged ink. Careful attention of the operator to the squeegee parameters is very important to obtain good quality images with no ghosting and smearing effect. The non-imaged ink is recycled by pumps and sent back to the ink injection station. A lot of image defects encountered up to now are caused by dust particles caught between the squeegee and the imaging drum. New procedures already underway to remedy this problem have greatly reduced the occurrences of squeegee scratches.

5. Transfer roller

The transfer system is a pressure roller made of a hard polyurethane roller. After revealing the image, the water content of the dots is still high so that cold pressure is used to transfer the wet image to the paper. The pressure applied is 100 Kg/cm^2. The image dries instantly by evaporation and absorption in the paper. This eliminates the need for heating units between colors. The image after transfer is also very scruff resistant, allowing the web to wrap around turnover bar without spoiling the image.

6. Cleaner

After having transferred the image on paper, the oil and ink residues are then cleaned by water-jets mixed with soaps to remove the excess ink and the oil coating applied on step 1. Control of the cleaning station is very important because most problems such as mottle, bad image transfer, ghost images are caused by cleaning failure of the imaging drum surface. The advantage of such a cleaning system, once optimized, is that each printing cycle starts on a fresh basis and no cumulative effect alters the printing parameters during long print-runs. The cleaning solution is kept in recycling tanks and can be used for many printing sessions.

Up to now the apparatus just described has brought the Elcography technology to the following performance levels:

Printing speed

The first amazing characteristic of the Electrocoagulation reaction is that it seems to be occurring in a time frame of the order of nanoseconds. The shortest interval where we can see printed dots is 100 nanoseconds. Typically the density is modulated by varying timing up to 4 microseconds where we obtain a maximum optical density of 1,75. The time density relationship is very stable and will be replicated over and over as long as chemical and physical parameters are not changed. This gives us a sort of constantly renewed image master system in the same fashion as a computer raster display which is constantly refreshed by video memories.
Current operational printing speed of the Elcography technology is 1 meter per second. On a 17 inches wide press with 8 color units, this speed translates in productivity of 25,500 letter size full-color duplex pages per hour or 51,000 sides per hour.

With current design of Elcographic print engines, the potential speed of 3 meters per second is a reachable goal that will be addressed by our R&D team in the coming years.
This high potential for speed upgrades is due to the extremely fast reaction time of the electrocoagulation phenomenon. A maximum density dot is imaged in 4 microseconds. This is equivalent to an imaging frequency of 250,000 dots per second with a single addressing node (1 second divided by 4μs). With a 200 dpi (8 dots/mm) resolution, this means a linear speed of 31 meters per second. (250,000 divided by 8 dots/mm = 31.25 meter per second). At 400 dpi (16 dots/mm) the potential speed of the imaging process is 15 meters per second (3000 feet/minute).

Of course, writing the image is only one part of the process and peripheral stations such as conditioner, cleaner and transfer have to be tested at such speeds. Electronic throughput limits have also to be considered, although, as will shown later, the technology is very efficient in its use of memory transfer bandwidth.

Dynamic Printing

Contrary to most high speed processes currently used in the trade, Elcography® is a fully dynamic printing technology where image information can be modified on-demand. In fact, when the image is being transferred to paper, the data being written by the printhead is already a different image. The advantages of dynamic printing are getting more obvious with the ongoing database marketing methods adopted by mainstream businesses.

Resolution

Addressing resolution is 200 dots per inch and each printed dot can assume 256 different grey levels. This dynamic range is not the electronic dynamic range but the optical density readings of a printed grey-scale. Contrary to half-tone printing, there is no inverse relationship between addressability and final half-tone resolution. Image quality at 200 dpi is said to be of photographic quality.

As can be seen in Figure 4 Elcography® clears out the visual limit curve. This curve shows the relationship between the human eye visual response and the possible gray levels available per printed dot. Binary systems like offset will need a minimum of 2000 printed dots per inch to reach out this curve at 200 lines per inch and 100 gray levels.(Kotera, 1995)

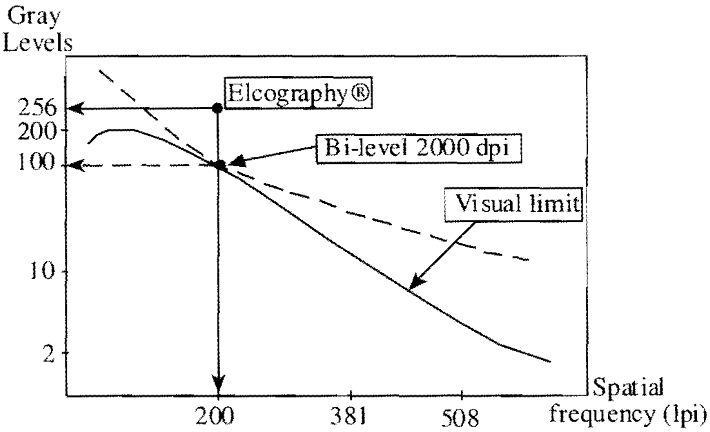

Figure 4: Relation of gray levels and visual limit

Even if Elcography® addressing resolution is only 200 dpi, text appears to be of near typeset quality for most printing applications especially with the smoothing filters used when rasterizing the files.

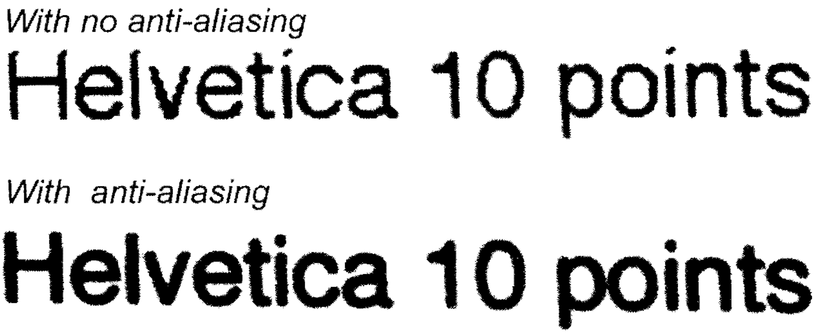

Figure5: Elcography® text quality with font smoothing

For lower size type fonts under 6 points and also for kanji characters, addressing resolution will probably need to be increased to 300 dpi.

Continuous-tone

It is a well known fact that in printing, there a two fundamental ways to reproduce half-tone information: one can vary the ink surface coverage or the volume of ink applied to paper. We call the first method surface modulation and the second method volume modulation. In general, if you can control the thickness of the ink you can do it in very fine increments. Elcography® uses the volume modulation method by varying the ink thickness as well as the dot diameter. The ink volume modulation is obtained by varying the time lapse of the electrode activation. Minimum densities of 0.03 have been observed with a 100 nanosecond gate opening and maximum densities of 1.75 with a pulse width of 4 microsecond.

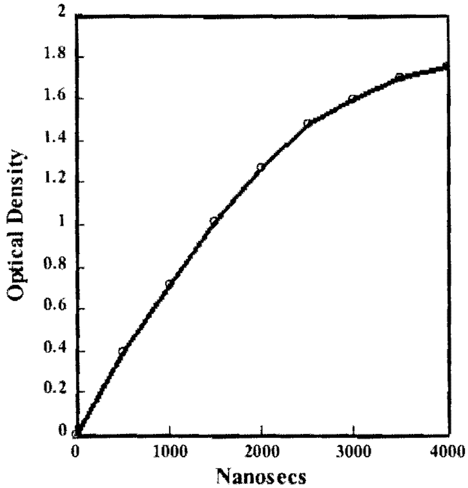

Figure 6 :Typical density curve of electrocoagulation printing

With such fine increments the process is generally classified as a true continuous-tone printing process. Other examples of true continuous-tone printing processes are thermal dye sublimation, collotype and conventional gravure. Elcography is the only printing technology that is both dynamic and contone.

Bandwidth efficiency

The contone method used in Elcography is also crucial for high-speed variable printing because it determines the required data bandwidth the electronic circuits have to sustain to feed the printer continuously. For instance, an Elcography® printer with 200 dpi resolution over a 17 inches wide web and 256 gray levels per dot, running at 1 meter per second needs a bandwidth of 107 Megabytes per second. This is roughly three A3 pages per second.

A surface modulation system that would reach the high quality level of offset printing would need to print at least 1500 dots per inch to obtain a 150 line screen image with 100 grey levels. This is equivalent to 112 MegaBytes for a four-color 11.75" X 17" page.(Ariniello, 1984) Now if one has to print three of these pages in one second, one needs to transfer the raster data from digital memory at 675 MegaBytes per second. Clearly this is not a practical proposition even for future electronic systems.

The only way to reduce bandwidth while keeping all the grey scale information is to print at lower resolutions but higher pixel depth. Elcography achieve this trick by controlling the grey-scale information for each dot, thus allowing 1 meter per second printing with standard off-the-shelf circuits operating at a far more reasonable rate of 26 Megabytes per second per color.

Format flexibility

Press width of 11, 17 and 24 inches are feasible in the current state of the art. The imaging cylinder being seamless, the cut-off is determined by the amount of electronic buffer memory coming with the press. In master plate systems, paper waste can be a significant cost factor because of page counts that do not fit the full press cut-off . With a dynamic printing system the format flexibility in the web direction eliminates totally this kind of waste even when customer layout is not standard.

Workflow

Typical pre-press workflow for Elcography® presses will be as following:

- Page assembly by desktop programs
- Four-Color separations
- Ripping, which can be done on non-proprietary software, is simplified because of the low spatial resolution needed to convey high image information content to paper. In Elcography, four-color A3 frames occupy 32 MegaBytes of memory. There is no special screening needed, the image is a replication of the continuous-tone image in the frame buffers. Text data is rasterized with anti-aliasing algorithm that smoothes the font type by giving smaller grey values to the edge of the type. Typical ripping times with a 166 MHz Pentium system is under 1 minute for A3 four-color postscript files.
- The pre-rasterized images are then sent to a read-write memory even when the printer is busy printing the previous job. The raster files transfer for an A3 double-sided four-color job to the print server memory is around 30 seconds with current mainstream desktop computer technology.
- The press prints from the memory buffers until the end of job signal.

Paper range

Most uncoated offset, bond, velum, ink-jet are already giving good results. Newsprint is also a very good substrate. A special coated paper designed for Elcography® gives excellent transfer and finish approaching photographic rendering quality. Undergoing research and testing results show good promise for the widening of image transfer efficiency on other types of paper and synthetic substrates.

Operating costs

With current technological parameters cost per print is expected to lie in the vicinity of medium-run offset. Although Elcography digital presses are currently slower than web offset presses their operating costs are likely to be very competitive because they require no printing plates and make-ready is minimal.

Applications

Elcography®, at its current stage of development, will mostly contribute to reduce costs in the short-run printing markets defined as under 10,000 copies. Markets already using newsprint in small formats will particularly benefit from Elcography® print-run flexibility and the elimination of film and plate costs.

In future developments the technology will also be oriented towards new way of providing information on paper such as for instance:

- Internet Printing: A lot of speculations about the future of printing services are underway because of the Internet method of delivering information. It is our contention that a fully dynamic color printing system such as Elcography® will complement the electronic information diffusion methods. For instance someone consulting an electronic catalog might want to see the final result of his search and queries assembled on paper. By keeping track of his inquiries the catalog company sends the pages to a remote digital printing center and sends the results to the customer. This on-demand scenario is not feasible on computer to plate systems but it is for direct printing systems with sufficient throughput.

- Custom publishing: Publishing firms can use digital printing by offering a publication closer to each reader specific interests. Software search agents can do the legwork for the reader and supply information on paper substrate.

- Decentralized printing: The distribute and print model has not yet gathered momentum but it is a question of time before such schemes catch on in the industry. The right mix of high printing speed, low image memory requirements and low operating cost has to be designed. There is most likely a digital printing speed threshold where decentralized printing will be more economic than centralized printing.

Conclusion

Elcography long-run printing tests have shown just recently, that it has strong potential for the transition of high volume printing to a fully digital integration. A lot of efforts remain to be done regarding color space standardization, paper testing, image artifacts elimination and speed and resolution increases. For the time being, the technology has now reached a level where some printing applications can greatly profit from the elimination of pre-press and make-ready costs.

References

Ariniello, R.M.:

1984. Application of a high performance optical subsystem to graphic arts image storage, TAGA, p.612.

Castegnier, A.:

1973. U.S. Patent 3,752,746, (August 14 1973)

1975. U.S. Patent 3,892,645, (July 1 1975)

1985. U.S. Patent 4,555,320, (November 26 1995)

1987 U.S. Patent 4,661,222, (April 28 1987)

1987. U.S. Patent 4,680,097, (July 14 1987)

1988. U.S. Patent 4,764,264, (August 16 1988)

1990. U.S. Patent 4,895,629, (January 23 1990)

1995. U.S. Patent 5,449,392, (December 9 1995)

1995. U.S. Patent 5,472,744, (December 5 1995)

Kotera, H.

1995. Image Processing and Printing Methods, IST Advance in Non-impact Printing, p.13.

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