NEW HIGH SPEED DIGITAL PRESS PLATFORM USING ELECTROCOAGULATION PRINTING

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Abstract: This paper will describe a new digital printing based on the Electrocoagulation of an electrolytically sensitized polymeric water-based pigmented ink. This unique system is printing variable thickness dots directly from digital input supplied in real-time by electronic memories. This computer-to-ink platform is composed of multiple shaft-less printing groups and prints 25,000 four-colour double-sided magazine pages per hour.
Operational parameters of the platform will be described as well as the fundamental differences with conventional printing processes. Suitable paper properties for electrocoagulation printing will also be explored.

Introduction

Invented in 1971, and developed since 1984 by Adrien Castegnier, the electrocoagulation printing process has evolved in a full-fledged digital printing solution offering continuous-tone printing at the very high speed of 1 meter per second.

The main steps of Electrocoagulation printing systems are:

1. The cleaning of imaging surface,
2. The oil conditioning of imaging surface,
3. The free-flow ink injection on imaging surface,
4. The ink electrocoagulation by cathode activation,
5. The image revealing by squeegee blade,
6. The direct image transfer from imaging surface to receiving substrate.

These steps were documented in other publications (1), (2) and we will concentrate, here, on the main ink electrocoagulation reaction.

Ink Electrocoagulation

Electrocoagulation is a very efficient mean of discriminating image sites by a localized cross-linking of a polymeric ink, the amount of cross-linked ink being controlled by the time window of the electrolytic circuit.
The electrolytic ink is a mixture of water, polyacrylamide (PAM) pigments and conductive elements. A characteristics of polymer filaments is that they are very flexible along their length. Water is a very good solvent of PAM, which is why

the latter is often used in agriculture to keep the top soil layer humid. Also PAM chains are not very stable in water. This makes the polymer network very sensitive to small perturbations. In the case of electrocoagulation, ferric ions are the factors causing the polymer network collapse on the anodic imaging cylinder (3). Ferric ions or trivalent ions (Fe^{3+}) were already known for their high cross-linking efficiency on gelatin material (4). Electrocoagulation research undertaken by Elcorsy and Toyo ink has now documented the trivalent ions cross-linking effect on synthetic macromolecules such as polyacrylamide. These ferric ions are released from the anodic imaging cylinder surface when an electrolytic circuit is closed by selective cathode activation. In the electrolytic cell thus created, chlorine is generated at the anode surface and is reducing the anode passivation layer. A sort of selective dissolution then takes place where the ferric ions jump into the ink solution and capture the polymer strands and retain the pigment material.

The dissolution occurs in very small amounts so that the imaging cylinder is lasting millions of printing cycles. More important the dissolution doesn't change the imaging cylinder electrocoagulation properties, so that the image densities stay in very stable conditions even for long runs provided ink batches are uniform.

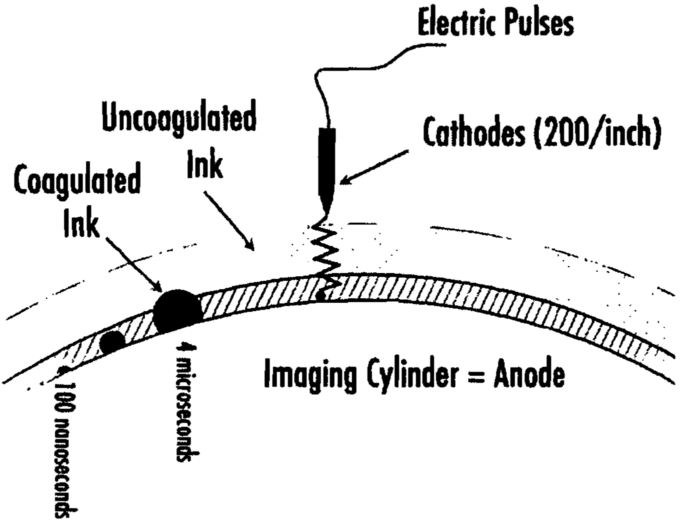

Figure 1. Electrocoagulation ink writing

Figure 1 above is a schematic representation of the coagulated dots still embedded in the uncoagulated ink. The latent dots of different thickness are grafted on the imaging cylinder while the surrounding ink sites have no adhesion to the imaging cylinder.

Based on these basic research findings, Elcorsy's team of designers have elaborated a complete printing platform, called model 200, with the following design parameters.

Mechanical issues

- Model 200 was designed as an 18" web press so as to print a two-up magazine signature or a tabloid page in landscape mode.
- Since the ink densities are controlled instantly by electronic circuits the press doesn't need to start at lower speed and ramp-up to reach equilibrium color density. This is why the press can have a fixed printing speed of 200 feet per minute and reach the required density on the first print.
- The press configuration can be modular, and can easily be upgraded from a single printing engine to an eight color (4/4) configuration.
- Independent programmable driving motors with adjustable speed can be coupled with web tensioning sensors. Since the paper web is driven by NIP between the imaging cylinder and the transfer roller, the web tension can be controlled by adjusting in real-time the speed of motors driving the imaging cylinder.
- Most of the parts around the printing engine are made in stainless to avoid any potential long-term corrosion problems.
- Frame parts were built very thick to guarantee constant gap between the cylinder and the print heads when the counter pressure is applied by the transfer roller on the imaging cylinder.
- The conditioning system applies a controlled layer of oil on the imaging substrate.
- The ink injection system is also very simple. The ink is filling the electrodic gap between the cathode array and the rotating anodic imaging cylinder.
- Because the coagulated dots are composed of the cross-linked polymer strands with a different cohesiveness than the ambient solvent, a simple rubber squeegee system was designed to separate both ink phases.
- The platform uses a direct method of transfering the image on paper. The paper passes through a hard NIP where high pressure is applied by hydraulic piston.
- The cleaning station uses water and soap to clean the imaging cylinder from oil residues and non-transferred ink. The cleaning solutions are totally recyclable.

Electronic architecture

Elcorsy's development work was based since the beginning on the philosophy to make the press print continuously during long time periods. In a dynamic printing system the memory serves as a kind of electronic plate. It contains bit-map data that is sent in real-time to print head driver circuits. It is the most critical component for a non-stop printing mode.

The electronic architecture was thus designed entirely with solid-state memories coupled with an industrial microprocessor and a real-time operating system that will minimize press stoppages. Even if the computer operating system crashes, the data should still be transferred in the buffer memory and carried to the print head circuits without restarting the computer.

Solid state memory architecture was preferred because the heavy duty printing volumes required by the Elcography digital press restricted the use of hard disk memory to the archiving of pre-rasterized images. Current mainstream network protocol Ethernet 100BaseT has been tested and was shown to support sustained transfer rates of 5 MegaBytes/second. The required throughput at current printing speed of 1 meter per second is 27 MegaBytes/second for each color or 108 Megabytes/second for four colours. Because of this discrepancy, the real-time functions of feeding and processing the image data to the printhead had to be separated from the input workflow. By doing so future developments in faster input bus standards such as Gigabit Ethernet will be integrated in the print server architecture with minimum design changes in the output bus.

The mass memory system was designed with electronic collating capabilities. A book is thus imposed sequentially in the buffer memory which feeds the printer continuously to print a complete book on the continuous web.

As was previously explained, coagulated dots on the cylinder can assume different diameter and thickness. When transferred on paper, the dot diameter and density will vary with each paper's transfer efficiency. By building electronic transfer curves in the electronic circuits, the dynamic press is able to conform to a wide range of papers without any mechanical adjustment in the ink injection mechanism. Because the density is controlled electronically at the dot level, the same image can be output on different papers with no other intervention than selecting the appropriate paper type in the print menu prior to printing. The printer transfer curves can also be modified on-line in case paper surface quality varies on the same roll.

Speed and parallelism

The electrocoagulation phenomenon can be observed at time intervals as low as 100 nanoseconds for minimum densities and 4 microseconds for maximum densities. A single cathode can address the ink at a 250 kHz maximum frequency. When printing at 1 meter per second, each cathode prints at a maximum of 4 microseconds every 128 microseconds. Driver circuits are connected to multiple addressing cathodes. By increasing the level of driver circuit parallelism, and keeping the same frequency per dot, higher writing speed can be reached.

Resolution and dynamic range

The cathodes which are made of very thin conductors which convey the electric field to the ink. Actual resolution is 200 cathodes per inch. By varying the time lapse of each cathode activation the printhead can modulate the tickness as well as the diameter of the coagulated dots.
The maximum dot diameter is 190 µ. Since the space between cathodes is 75µ the D^{max} coagula are joined together and form an homogeneous layer. Only in the highlight areas, coagulated dots are separated by white space.

Tone modulation is thus a mixture of dot diameter variation and dot density variation, although the dominant effect is truly the dot density variation. The fact that maximum density dots are overlapping is useful for the rendition of type characters. If this was not the case there would be voids in the body of the type.

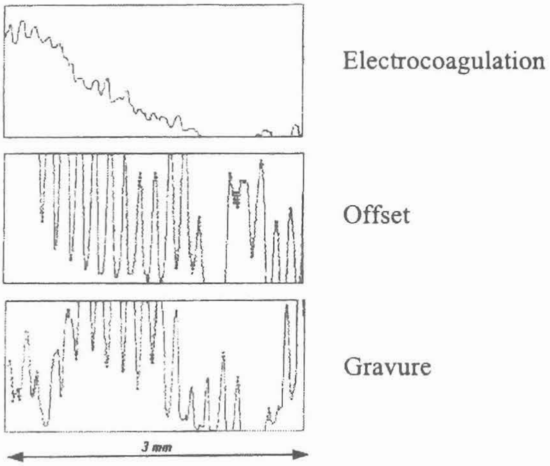

Figure 2. Density profiles of electrocoagulation vs offset and gravure

As for image quality, the contone method is similar to photographic rendering Reading density profile readings as in figure 2 of an Elcography® print along the x axis shows a continuous scale from one density level to another. For binary half-tone systems, such as offset and half-tone gravure, the density profile show strong discontinuities between dots.

Paper compatibility

A wide range of papers is compatible with electrocoagulation printing.
Papers types such as newsprint, groundwood, gravure, gloss coated or matte coated, ink jet, light weight coated, cast coated, synthetic papers and a good proportion of bond papers. Porous and rough surface papers are the least compatible where some white speckles typical of gravure printing appear sporadically on the printed images (5).
Typical D^{max} values obtained are 1.0 for newsprint, 1.30 for matte coated, 1.30 for light weight coated, 1.50 for Teslin papers and 1.50 for cast coated papers.

Dynamic Printing vs Static printing

We have described in the previous sections, a new digital printing system with most interesting features such as dynamic output capabilities, excellent half-tone, wide range of compatible papers and fast throughput. Such a system is a serious proposition for the development of new methods of decentralized document distribution. To understand to which degree the printing and publishing industry will adopt such a tool, we can first compare the general advantages and weaknesses of static and dynamic printing in table 1.

Printing Parameters	Static printing	Electrocoagulation
Speed	1000-3000 feet/min	200 feet/min
Make ready	15-60 minutes	1 second
Resolution	150 lpi	200 lpi
Half-tone levels	100	243
Registration system	Print and correct	Correct and print
Proofing	Off-press	On-press
Repeatability	Excellent	Good
Ink composition	Oil, pigments, waxes	Water, pigments, polymer
Ink setting	Slow	Fast
Other Chemicals used	Silver-halide chemicals	Water, soap, olefin
Ink thickness	5-30 microns	4 microns

Table 1. Printing parameters comparison

What stands out from this table is that static printing has an edge in burst printing rates. The dynamic printing system has a lower cruising speed but zero make-ready so that real productivity is higher than a comparable speed in static printing system especially in lower print-runs.

This higher productivity can also be seen in the figure below where the number of jobs per day can be very high in dynamic printing and decreases according to print-run quantity required.

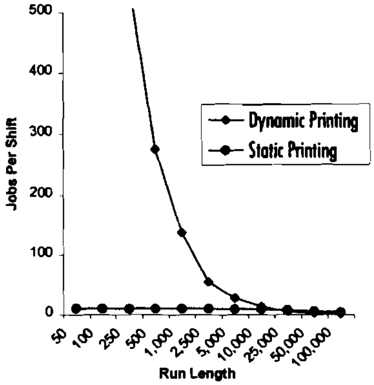

Figure 3. Number of jobs per shift as a function of print-run.

Another way to see the fundamental difference between dynamic and static printing is to plot production time in function of printing volume. The typical production curve for dynamic printing are directly proportional to quantities while in static printing the time to produce a certain quantity depends on a make-ready constant and the inverse of the printing speed of the press.

This relationship between print-run and production time can be stated in equation (1) for the dynamic printing case :

$$T_d = \alpha_d Q \qquad (1)$$

And equation (2) for the static printing case:

$$T_s = M + \alpha_s Q \qquad (2)$$

Where,

M: Make-ready time,
α_d: time units required to produce a single dynamic print,
α_s: time units required to produce a single static print.

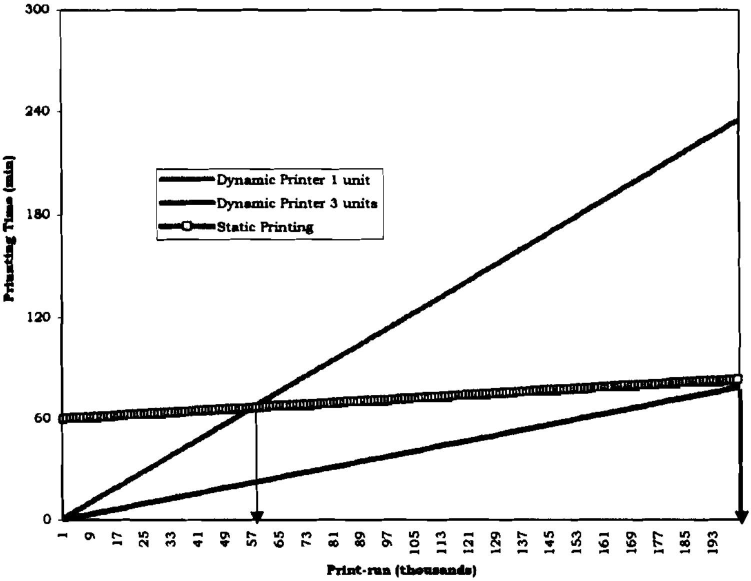

Figure 4. Printing time break-even dynamic printing vs static printing

One can see from figure 4 that the cross-over quantity where static printing becomes faster than a dynamic press is around 60,000 prints. Now this cross-over can be changed by spreading dynamic presses in different locations along the distribute and print model. The print-run level where static printing and dynamic printing have the same productivity is then higher (around 200,000). This graph shows the necessary condition for a viable decentralized printing proposition. But it is not a sufficient one.

The economics of the systems usually decide which mode of production is the most viable. Some components of the cost equation put some weight towards the decentralized printing scenario such as :

- distribution costs which are expected to be lower in dynamic printing mode.
- make-ready & pre-press costs are minimal compared to static printing.
- paper waste is bound to be lower.

But the following factors are weighing the balance towards the centralized static printing :

- manpower cost share will most likely be lower than digital printing, a 5 person team driving an offset web will cost less than a team of 10 persons in different locations.
- a web press installation is much more productive, operating at 2000 feet per minute instead of the 200 feet per minute of current speed of Elcography® presses. Even 8-page sheet-fed presses are now printing over 120,000 pages per hour, twice the speed of electrocoagulation.
- supervision costs such as planning and quality control are usually lower when centralized.

These last two points are large obstacles to the distribute and print scenarios. Also some uncertainties still remain in the evolution of the cost of transmitting digital files to a large number of printing centres at the same time.

To which extent a particular job can be decentralized will depend on the total circulation needed.

A simple model can provide such rule of thumb information and can guide technical experts in their planning towards network printing schemes.

The goal of this model is to find the print volume that equalizes the total cost of printing and distributing in static printing vs dynamic printing. By varying the distribution cost parameters we will then observe its effect on the print volume range that can be decentralized without cost penalty.

The starting condition is thus that :

$$C_d = C_s \qquad (3)$$

With,

C_d : Dynamic printing total cost including distribution,
C_s: static printing total cost including distribution.

When each cost curve is detailed we then have the equation:

$$H_d T_d + (D_d + I_d + P_d)\, Q = H_s T_s + F + (D_s + I_s + P_s)\, Q \qquad (4)$$

and replacing the production time by its value we rewrite the equation as :

$$H_d\ \alpha_d Q + (D_d + I_d + P_d)\, Q = H_s M + \alpha_s Q + F + (D + I_s + P_s)\, Q \ (4')$$

where,

H_d : Hourly cost of operating a dynamic press,
H_s : hourly cost of operating a static press,
D_d: distribution cost rate of dynamic prints,
D_s: distribution cost rate of static prints,
I_d: cost rate of ink per dynamic print,
I_s: cost rate of ink per static print,
P_d: dynamic cost per piece of paper,
P_s: static cost per piece of paper,
M: make-ready time associated with static printing.

Solving equation (4') for (Q) gives us for the break-even print quantity where a dynamic press will be as cost efficient as static printing presses.

$$Q = F + H_s M / (H_d\ \alpha_d - H_s \alpha_s + D_d - D_s + I_d - I_s + P_d - P_s) \qquad (5)$$

Given that in dynamic Elcography® printing the following relationships are generally true:

$H_s > H_d,$	means that the hourly cost rate of the dynamic press is lower,
$\alpha_d > \alpha_s,$	means that the printing time is longer for dynamic printing once the set-up is done,
$D_d - D_s < 0$	represents the difference in distribution cost for static printing.
$I_d - I_s = 0$	states,for simplicity of the argument, an equal cost of ink.
$P_d - P_s = 0$	although paper costs should be lower in dynamic printing because no waste is generated for make-ready we assume here the same paper cost for simplicity of the argument.

Equation (5) is now simplified to the following expression :

$$Q = F + H_s M / (H_d\ \alpha_d - H_s \alpha_s + D_d - D_s) \qquad (5')$$

The higher negative difference in distribution cost (D_d - D_s), will lower even further the difference in running costs value ($H_d\ \alpha_d$ - $H_s\ \alpha_s$) and the higher will be the crossover print volume between dynamic and static printing.

We now know that the lower distribution cost of dynamic printing should mean higher break-even quantities. The question remaining is how sensitive is the break-even level to this difference in distribution costs?

We assume some arbitrary values for the parameters in equation (5') such as:

1. a static printing make-ready time of 1 hour,
2. a static printing speed of 2,000 feet per minute,
3. a dynamic speed of 200 feet per minute,
4. a basic hour cost rate of dynamic printing that is half the rate of static printing,
5. The distribution cost rate in static printing is equal to the printing cost rate.

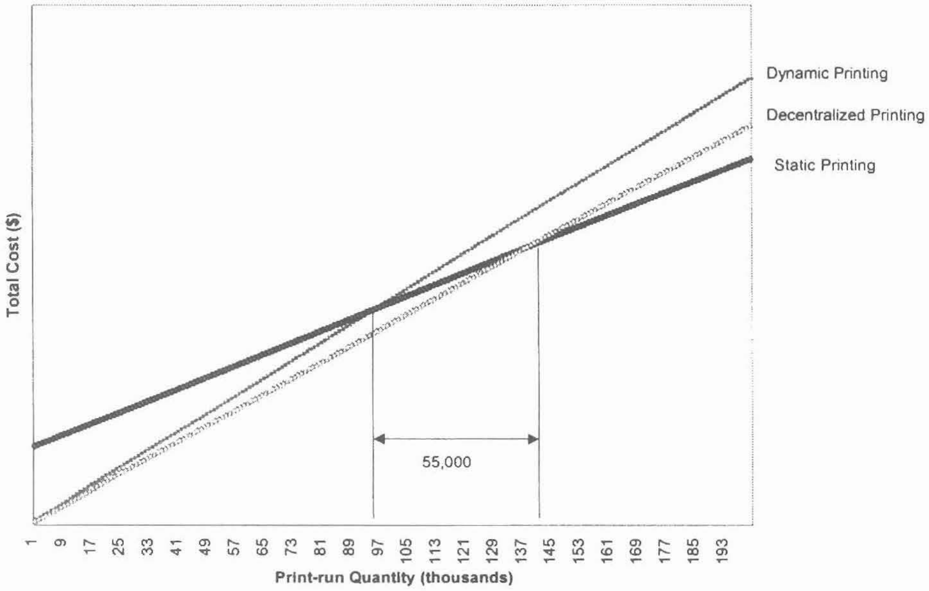

Figure 5. Decentralized vs centralized printing cost

One can then build three sets of typical cost curves:

1. a static printing cost curve,
2. a dynamic printing cost curve where distribution costs are assumed to be equal to static printing distribution costs,
3. a decentralised printing cost curve where dynamic distribution costs are a certain fraction of the static printing distribution costs.

In figure 5 above, the decentralized distribution costs are assumed to be one tenth (1/10) of the static printing distribution cost. This shifts the changeover point by a quantity of 55,000. The shift appears to be substantial but the hypothesis of the dynamic costs being one tenth of the static costs is rather drastic.

A safe interpretation of the figure 5 is, that to make network printing work in medium to large volume publishing it would require higher dynamic printing speeds even if distribution costs are lower.

From past tests undertaken in Elcorsy's labs, the Electrocoagulation printing technology has a strong probability to reach the printing speed necessary for large-scale decentralization of document distribution.

Conclusion

The development of the basic electrocoagulation printing technology has brought the concept of dynamic decentralized printing closer to reality. Although the actual state of the art in electrocoagulation dynamic printing is not yet sufficient for complete decentralization, it appears to be a sound base for planning successful introduction and testing of networked document distribution concepts.

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