Electrostatic Marking Technologies Recent Advances and Future Outlook

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Abstract

Electrostatic marking technologies continue to be invented in response to customer needs. Technologies which have been introduced during the last decade will be reviewed and the outlook for the near future will be considered.

I. Introduction

In response to customer needs, electrostatic marking technologies, which encompass development systems used in electrophotography and ionography, have advanced significantly in recent years. The customer needs of low cost and color have provided the driving force for the emergence of a surprising number of new marking technologies. Those technologies which have been introduced into the marketplace in the last decade are reviewed in this paper.

Historically, in the period 1952-1978, new electrostatic marking technologies emerged approximately every five years: (1) Liquid development which was introduced in 1955 by Metcalfe[1] and in 1957 by Strongham and Mayer,[2] continues to be of interest to the electrophotographic and ionographic community. (2) Cascade development,[3] invented in 1952, appeared in the first copier products from Xerox, including the famous Xerox 914 copier. (3) Magnetic brush development,[4] invented in 1957, was used in Electrofax products in the early 1960s and electrophotographic products in the early 1970s and continues to be the most used marking technology for high end electrophotographic products. (4) The conductive version of the magnetic brush system[5] was introduced in 1975. (5) Finally, monocomponent development (based on magnetic, insulative toner which jumps a gap) was introduced by Canon[6] in 1978 after many years of work in many laboratories. All of these marking systems, except cascade development, are used in currently available products. These five marking technologies, introduced over a period of 26 years, suggest the emergence of new marking technologies will occur every five years, on average. How wrong it is to make such simple extrapolations is shown below.

The marking technologies which were developed after 1985 in response to the customer needs of low cost and color are described in Section II. In Section III the results of this review are summarized and an attempt is made to predict where future advances may occur.

II. Recent Advances

A. Low Cost

It was recognized that the introduction by Canon of a monocomponent development system, in which the large carrier particles were eliminated, would be key to offering low cost copiers and printers. To allow participation in this market, alternative monocomponent development systems were introduced in 1985 by both Ricoh[8] and Toshiba[9]. These were based on nonmagnetic toner (as compared the Canon system, based on magnetic toner). The Ricoh system is a contact system which has been commercialized by Ricoh, IBM, and Lexmark; the Toshiba system is a jump system which has not been commercialized. This monocomponent marking technology has allowed both Ricoh and IBM/Lexmark to offer low cost copiers and printers competitive with those based on the Canon magnetic-toner jump system.

At the high speed end of the market, new marking technologies have been developed to minimize the cost of printing. In 1986 Delphax Systems[10] introduced a new form of ionography, in which the latent image is created by selectively shuttering ions, resulting from an air breakdown, by a screen electrode. This development system uses yet another monocomponent system based on conductive toner. Although it minimizes the charge needed for the latent image, it requires pressure transfer due to problems of electrostatically transferring conductive toner at high relative humidity. This technology has the advantage of eliminating the photoreceptor; it also has difficulty achieving the resolution that electrophotography has demonstrated.

Alternative powder marking technologies continued to be explored to achieve lower cost. Some that have been recently reported, but not commercialized, include:

1. A one step direct marking process[11,12] in which toner on a donor roll is attracted to paper with a dc electric field. The stream of toner particles are imaged by causing the toner to pass through apertures which are opened and closed electronically with fringe electric fields. Array Printers of Sweden calls this technology "Toner Jet". They claim 300 dpi, 50 cm/s operation. Grey scale is also possible by controlling the magnitude of the voltage on the wires. Periodic cleaning of the wires and multiplex operation have been discussed.

2. A printer using only two steps can be built by image-wise exposing a uniformly charged toner layer to charged ions from an ion print head, thereby changing the sign of the toner which will form the real image. The toner is then transferred to paper by electrostatic attraction.[13]

3. A method of combining the steps of cleaning, charging, exposing, and developing into one was suggested.[14] In this concept, the photoreceptor is charged and exposed while it is in the development zone. Conductive magnetic toner is used. The conductive toner brush charges the photoreceptor at the nip entrance of the development system, and image exposure at the nip exit through the back of the pho-

toreceptor establishes the latent image to which the conductive magnetic toner adheres. Similar ideas using conductive magnetic brush development were suggested by Kimura et al.[15]

4. In magnetic cascade development,[16] magnetic monocomponent toner is placed between the photoreceptor and a smooth counter-rotating roller, both of which have internal stationary magnets. The magnets behind the photoreceptor cause toner to uniformly coat the whole photoreceptor surface in the prenip region. Toner in the background regions are repelled in the nip.

B. Color

The most activity in new marking technologies has occurred in response to the need for color. Color copiers and printers require (1) improved quality, as compared to black and white, (2) image accumulation on either paper, the photoreceptor or on an intermediate surface and (3) minimization of physical size. These needs required the invention of many new marking systems.

B.1 Improved Quality

The development system is probably one of the most difficult systems of the electrophotographic process to make uniform and stable. Uniformity is affected by low and high frequency image noise, some of which can be traced to the brush profile in the magnetic brush development system. History effects cause image defects at the leading or trailing edge of solids in some magnetic brush development systems and lines perpendicular to the process direction separated by one development roller circumference in some monocomponent systems. Lack of stability results from any change in the many parameters which affect development.

In principle, one would like very reproducible development, with no image defects. This suggests the need for a very efficient system which develops to neutralization, a condition which makes the developed mass per unit area sensitive to the least number of hardware and material parameters. Such a condition is approached by a development system invented by Eastman Kodak for the ColorEdge copier and also by liquid development.

Eastman Kodak, in designing the ColorEdge copier, which is the fastest available color copier today (23 full color pages per minute) actually faced two challenges. (1) If the efficiency of the development could be increased so that neutralization was approached, the image quality would be improved, as mentioned above. (2) Furthermore, they wanted to use one of their existing black and white copier engines (the Ektaprint 150) so that a new engine did not have to be designed. This required putting three development systems where one existed before. To accomplish these goals, they invented a new development system.[17] In this system, which is a modified magnetic brush development system, small diameter (≈30µm) permanently magnetized spherical carrier beads, with electrostatically attached toner, are attracted to a roller inside which magnets rotate. The rotating magnetic field tends to move those carrier beads which have lost their toner particles, and are consequently charged, away from the latent image. Recall that these charged beads, if not moved away from the latent image, limit toner development because they reduce the electric field in the development zone to zero (see Chap. 6 in Ref. 7).

A liquid development system[18] can, in principle, develop to neutralization and has been used in very high quality prepress proofing systems. Most of these operate at very low speeds, many minutes per copy, and require special contained environments due to use of noxious solvents. In 1990, AM International announced a two-color 300 ft./min printer based on liquid development and recently Indigo[19] announced a 33 full color A4 page/min offset quality printer also based on liquid development. These products extend liquid development systems to high speeds.

Finally, improved image quality has been achieved in the standard magnetic brush development system. This has been achieved by reducing both the carrier and toner size. Gruber and Dalal[20] have suggested that reduced toner size leads to improved edge sharpness and reduced image graininess while reducing the overall pile height. Schein and Beardsley[21] noted smaller toner particles reduced edge raggedness. Chiba and Inoue[22] pointed out that smaller toner particles produce better gray scales, improvements of dot shape and less noise in the halftone dot area, an idea supported by recent work at Fuji-Xerox[23]. The use of smaller diameter carrier beads and small gaps for improved efficiency and reduced image noise can be found in the black development system in the Panasonic[24] color copier, among others. The black development system in the Panasonic color copier is a magnetic brush system with a smaller gap (400µm) than usual (1250µm).[24] A smaller gap gives higher M/A, simply because the electric fields are increased. The smaller diameter carrier beads lead to a secondary source of increased efficiency: the effective dielectric constant appears to increase as the carrier bead diameter is reduced.[25] Furthermore, small carrier beads increase the spatial frequency of image noise associated with the bead motion through the developed toner layers, reducing its perception by the eye. One negative effect of smaller diameter carrier beads is that charged carrier beads can more readily adhere electrostatically to the photoreceptor and be carried out of the development system. These must be captured with magnets prior to reaching the paper.

B.2 Image Accumulation

Where the colored toners are accumulated has major architectural and system implications. The choices are: on the paper, on an intermediate belt (or drum), and on the photoreceptor. One might expect that one of these choices would be preferable. However, all three have been implemented commercially.

The obvious first choice, and the one implemented initially by Xerox and later by Canon and Eastman Kodak, is accumulation on paper. Such an architecture can use well known development systems. It requires three or four transfers from the photoreceptor to the paper. Registration of the color images is a technical challenge.

To solve the registration problem, Colorocs Corporation suggested accumulating the toner images on an intermediate belt. Again well known development systems can be used.

Perhaps a more elegant solution is to accumulate the toner images on the photoreceptor as implemented by Matsushita Electric Industrial Co. in their Panasonic FP-C1 color copier[24] and by Konica in their 9028 color copier.[26] But this solution is also the most technically demanding for two major reasons: (1) Since the toner remaining on the photoreceptor is subject to recharge, wrong-sign toner in the background regions of the photoreceptor, which is normally rejected during electrostatic transfer, now has its charge changed to the correct sign (in the DAD process) and could produce excessive background. Therefore, the development systems, especially the black, must have very little wrong-sign toner. (2) Subsequent development systems must not disturb the already developed toner layers. Hence, they must be noncontact and non-interacting. As no such system existed, new development systems were invented. Panasonic and Konica have commercialized such systems. The Panasonic system is based on a monocomponent system with nonmagnetic toner which jumps a gap to the photoreceptor. Only dc voltages due to the latent image are used to cause the toner to jump from the roller to the photoreceptor, thereby preventing the mixing of toner that occurs in the presence of ac voltages. To dispense with an ac voltage required low average toner charge (≈3μC/g) and narrow charge distributions (to eliminate wrong-sign toner). The Konica system is a magnetic brush development system with a 150μm gap between the ends of the brush and the photoreceptor surface. To enhance development an ac bias of 1.4 kV p-p at 4 kHz is superimposed on the dc voltages[26].

B.3 Compactness

As mentioned above, the development system in the ColorEdge copier was designed with compactness in mind: three development systems had to fit where one fit in the black and white machine.

The Panasonic monocomponent color development systems are amazingly compact. They require only about 3.8 cm of surface length on the photoreceptor and are only 10 cm deep.

The recent announcement of the Ricoh Artage 8000[27,28] also describes the invention of a new more compact development system that combines monocomponent and two component development. In this system toner is loaded onto a roller, as in a monocomponent development system. The roller then supplies toner to the beads on a magnetic brush development system. The toner *Q/M* on the monocomponent roller is 2-5μC/g: by the time the toner particles are brought into the development zone the *Q/M* has increased to ≈20 μC/g The large volume reduction is due to the elimination of the large volume usually used for mixing the toner and carrier beads.

III. Summary

In response to the customer needs of low cost and color, there has been a rapid acceleration in the last decade of the invention and introduction of new marking technologies. Focusing on those commercialized, the need for low cost has driven the inventions of (1) monocomponent electrophotographic systems by Ricoh at the low end and (2) ionographic systems at the high end. The customer need for color has caused the invention of (3) the new magnetic brush system in the ColorEdge copier, (4) the extension of liquid systems to high speed by Indigo and AM International, improvement in the standard magnetic brush system with (5) small toner and (6) small carrier, (7) the noncontact nonmagnetic jump system in Panasonic color copier, (8) the magnetic brush jump system in the Konica system, and (9) the hybrid mono-dual system in the Ricoh Artage 8000.

This gives nine new systems introduced in the last ten years, or about one per year. This is a breathtaking increase of a factor of five over the prior twenty-five years! Clearly, the electrophotographic and ionographic communities have responded to the customers needs creatively and fruitfully. We can be proud of our accomplishment.

What will the next ten years bring? If we consider the driving forces of low cost and color, some idea of future trends is possible. The desire for an electrophotographic printer under $1000 has been achieved. Pressure to reduce costs further will of course continue, but I would guess change will occur more in manufacturing issues-simplifying and cutting costs-than in fundamentally new marking technologies. The desire for quality color printers and copiers has also been achieved. However, low cost color remains elusive. It is in this vein that I would expect invention. The technology trends suggest the needs here will be met either with a liquid or monocomponent development system. Liquid systems promise high quality, but the challenge of handling noxious fluids must be met. Monocomponent systems have promise of low cost, especially noncontact jump systems which accumulate the image on the photoreceptor, similar to the Panasonic concept. But technical challenges in reliability, quality, and tolerance control will need to be met.

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