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(54) A device for direct electrostatic printing (DEP) comprising a magnetic brush and printhead structure with special geometry

(57) A DEP device is provided that comprises :

a back electrode (105),
a printhead structure (106), at the front side of the receiving substrate (109),
an array of printing apertures (107) in said printhead structure (106) through which a particle flow can be electrically modulated by a control electrode (106a),
a toner delivery means (101), comprising a magnetic brush (103), comprising toner particles and magnetically attractible carrier particles, the reference surface of said magnetic brush being placed at a distance B (in mm) from the front of said printhead structure (106b), facing said magnetic brush, characterised in that

(i) a magnetic field is formed over said distance B
(ii) said magnetic brush has a curvature in the development zone fulfilling the equation I :

$$R \geqq \frac{C^2}{4.25B + 0.25} \qquad \mathrm{I}$$

wherein
the curvature R of said magnetic brush in the development zone is expressed as the radius (in mm) of a circle that best fits to said curvature of said magnetic brush in the development zone and C is the extension (in mm) of the array of printing apertures (107) in the direction of the movement of said receiving substrate (109) measured from the middle of the apertures in the first row to the middle of the apertures in the last row.

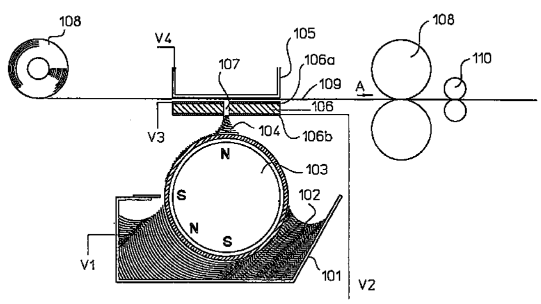

Fig.1

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Description

1. Field of the invention.

This invention relates to an apparatus used in the process of electrostatic printing and more particularly in Direct Electrostatic Printing (DEP). In DEP, electrostatic printing is performed directly from a toner delivery means on a receiving member substrate by means of an electronically addressable printhead structure.

2. Background of the Invention.

In DEP (Direct Electrostatic Printing) the toner or developing material is deposited directly in an imagewise way on a receiving substrate, the latter not bearing any imagewise latent electrostatic image. The substrate can be an intermediate endless flexible belt (e.g. aluminium, polyimide etc.). In that case the imagewise deposited toner must be transferred onto another final substrate. Preferentially the toner is deposited directly on the final receiving substrate, thus offering a possibility to create directly the image on the final receiving substrate, e.g. plain paper, transparency, etc. This deposition step is followed by a final fusing step.

This makes the method different from classical electrography, in which a latent electrostatic image on a charge retentive surface is developed by a suitable material to make the latent image visible. Further on, either the powder image is fused directly to said charge retentive surface, which then results in a direct electrographic print, or the powder image is subsequently transferred to the final substrate and then fused to that medium. The latter process results in an indirect electrographic print. The final substrate may be a transparent medium, opaque polymeric film, paper, etc.

DEP is also markedly different from electrophotography in which an additional step and additional member is introduced to create the latent electrostatic image. More specifically, a photoconductor is used and a charging/exposure cycle is necessary.

A DEP device is disclosed in e.g. US-P 3,689,935. This document discloses an electrostatic line printer having a multi-layered particle modulator or printhead structure comprising :

- a layer of insulating material, called isolation layer ;
- a shield electrode consisting of a continuous layer of conductive material on one side of the isolation layer ;
- a plurality of control electrodes formed by a segmented layer of conductive material on the other side of the isolation layer ; and
- at least one row of apertures.

Each control electrode is formed around one aperture and is isolated from each other control electrode.

Selected potentials are applied to each of the control electrodes while a fixed potential is applied to the shield electrode. An overall applied propulsion field between a toner delivery means and a receiving member support projects charged toner particles through a row of apertures of the printhead structure. The intensity of the particle stream is modulated according to the pattern of potentials applied to the control electrodes. The modulated stream of charged particles impinges upon a receiving member substrate, interposed in the modulated particle stream. The receiving member substrate is transported in a direction orthogonal to the printhead structure, to provide a line-by-line scan printing. The shield electrode may face the toner delivery means and the control electrode may face the receiving member substrate. A DC field is applied between the printhead structure and a single back electrode on the receiving member support. This propulsion field is responsible for the attraction of toner to the receiving member substrate that is placed between the printhead structure and the back electrode.

A DEP device is well suited to print half-tone images. The densities variations present in a half-tone image can be obtained by modulation of the voltage applied to the individual control electrodes. In most DEP systems large apertures are used for obtaining a high degree of density resolution (i.e. for producing an image comprising a high amount of differentiated density levels).

For text quality, however, a high spatial resolution is required. This means that small apertures must have to be made through said plastic material, said control electrodes and said shield electrode.

If small apertures are used in the printhead structure in order to obtain a high spatial resolution, then the overall printing density is rather low. This means that either the printing speed too is rather low, or that multiple overlapping rows of addressable apertures have to be implemented, yielding a complex printhead structure and printing device.

By using apertures with a large aperture diameter, it is also necessary to provide multiple rows of apertures in order to obtain an homogeneous gray density for the whole image.

Printhead structures with enhanced density and/or spatial control have been described in the literature. In US-P 4,860,036 e.g. a printhead structure has been described consisting of at least 3 (preferentially 4 or more) rows of apertures which makes it possible to print images with a smooth page-wide density scale without white banding. The main drawback of this kind of printhead structure deals with the toner particle application module, which has to be able to provide charged toner particles in the vicinity of all printing apertures with a nearly equal flux. In US-P 5,040,004 this problem has been tackled by the introduction of a moving belt which slides over an accurately positioned shoe that is placed at close distance from the printhead structure. In US-P 5,214,451 the problem has been tackled by the application of different sets of shield electrodes upon the printhead structure, each shield electrode corresponding to a different row of apertures. During printing the voltage applied to the different shield electrodes corresponding to the different rows of apertures is changed, so that these apertures that are located at a larger distance from the toner application module are tuned for a larger electrostatic propulsion field from said toner application module towards said back electrode structure, resulting in enhanced density profiles.

In US-P 5,327,169 and EP application 9420126 filed on April 14, 1994, a magnetic brush has been described as toner application module, using a two-component development system. Since the magnetic brush has a rather small diameter, the same problems are encountered, namely that multi-row printhead structures need density correction for said different sets of rows. Furtheron, if, as described in US-P 5,327,169, the printhead structure is bend around said magnetic brush the distance towards the back electrode is different for the different rows of printing apertures, yielding again deviations in density and sharpness of the image.

There is still a need for a DEP system comprising a printhead structure comprising multiple rows of apertures and a toner application module with appropriate geometry and dimension so that images with excellent sharpness and density profiles can be obtained in a fast and reproducible way.

3. Objects and Summary of the Invention

It is an object of the invention to provide an improved Direct Electrostatic Printing (DEP) device, printing with high density and high spatial resolution at a high printing speed.

It is a further object of the invention to provide a DEP device combining high spatial and density resolution with good long term stability and reliability.

It is still a further object of the invention to provide a printhead structure for a DEP device, wherein said printhead structure combines a compact design with good long term stability and reliability.

It is another object of the invention to provide a charged toner application module which combines a compact design with high printing speed and good long term stability.

Further objects and advantages of the invention will become clear from the description hereinafter.

The above objects are realized by providing a DEP device that comprises :

a back electrode (105),
a printhead structure (106), at the front side of the receiving substrate (109),
an array of printing apertures (107) in said printhead structure (106) through which a particle flow can be electrically modulated by a control electrode (106a),
a toner delivery means (101), comprising a magnetic brush (103), comprising toner particles and magnetically attractible carrier particles, the reference surface of said magnetic brush being placed at a distance B (in mm) from the front of said printhead structure (106b), facing said magnetic brush, characterised in that

(i) a magnetic field is formed over said distance B
(ii) said magnetic brush has a curvature, R, in the development zone fulfilling the equation :

$$R \geqq \frac{C^2}{4.25B + 0.25} \qquad \mathrm{I}$$

wherein
the curvature R of said magnetic brush in the development zone is expressed as the radius (in mm) of a circle that best fits to said curvature of said magnetic brush in the development zone and C is the extension (in mm) of the array of printing apertures (107) in the direction of the movement of said receiving substrate (109) measured from the middle of the apertures in the first row to the middle of the apertures in the last row.

4. Brief Description of the Drawings

Fig. 1 is a schematic illustration of a possible embodiment of a DEP device according to the present invention.
Fig. 2 is a schematic illustration of the development zone.
Fig. 3 is a cross-section of fig 2 along the plane A-A'-A''.

5. Definitions

Throughout this disclosure following definitions are used :

- "magnetic brush" is a magnetic brush of the stationary core (carrying magnetic poles)/rotating sleeve type and includes both cylindrical and non-cylindrical magnetic brushes.
- "curvature of the magnetic brush" is the curvature of the rotating sleeve of the magnetic brush, and the radius of the circle best fitting said curvature is measured from the middle of said circle to the surface of said sleeve.
- "reference surface of the magnetic brush" is the surface of the sleeve of the magnetic brush when NO developer is present on said magnetic brush.
- "development zone" is the volume between the printhead structure (106) and the toner delivery means (101), wherein the toner cloud (104) is formed. In Fig. 2, a non-limitative example of a development zone is given. It is the zone (volume) (111) between the printhead structure (106) and the reference surface of the magnetic brush (103), determined by the surface of said printhead structure (106) facing said magnetic brush, the perpendicular planes dropping from the edges of the array of printing apertures (107) to said reference surface of the sleeve (103b) of the magnetic brush and said reference surface itself (112) within the volume determined by said perpendicular planes.

6. Detailed Description of the Invention

In the literature many devices have been described that operate according to the principles of DEP (Direct Electrographic Printing). All these devices are able to perform gray scale printing either by voltage modulation or by time modulation of the voltages applied to the control electrodes. We have found that if reproducible density modulation at a certain spatial resolution has to be combined with a high printing speed, then both the geometry of said printhead structure and of said charged toner application module has to be adapted well to each other.

In has already been disclosed in European Application 94201026.5 filed on April 14, 1994, that, in a DEP device extracting the toner particles, to be deposited, directly from a magnetic brush, geometrical parameters have to be controlled. The European application cited above discloses that the distance between said magnetic brush and the printhead structure has to be matched to the length of the "hairs" on said magnetic brush for quality printing.

In order to be able to print at higher speed, it is necessary that a DEP device comprises a printhead structure with multiple rows of printing apertures. Since printing devices are preferably kept as small as possible, it is interesting to use, in any printing device, the smallest components possible. For that reason a magnetic brush with small diameter is preferably used in any electro(photo)graphic device. Magnetic brush assemblies with a small diameter of the outer sleeve are very interesting for their small size and low cost. However, it is very difficult to use a very small magnetic brush with a printhead structure that has multiple rows of apertures, needing a relatively wide development zone.

We have experimentally found that there is a maximum curvature (i.e. minimum radius) of the magnetic brush in said development zone that can give good print quality with a printhead comprising a given number of rows of printing apertures. Said given number of rows of printing apertures is in fact the extension of the array of printing apertures in the direction of the movement of the receiving substrate, measured from the middle of the apertures in the first row to the middle of the apertures in the last row. As a result of experimentation it has been possible to describe this maximum curvature (minimum radius) by equation I :

$$R \geqq \frac{C^2}{4.25B + 0.25} \qquad \text{I}$$

wherein the maximum curvature is described as the radius R (expressed in mm) of a circle that best fits to said curvature of said magnetic brush (103) in the development zone (111), B is the distance in mm between the reference surface of the magnetic brush (103) and the printhead structure (106) and C is the extension of the array of printing apertures (107) measured in the direction of arrow A, as described above.

Preferably R fulfils the equation II :

$$R \geqq \frac{C^2}{1.55B + 0.25} \qquad \text{II}$$

Most preferably R fulfils the equation III :

$$R \geqq \frac{C^2}{0.30B + 0.25} \qquad \text{III}$$

This relation between curvature of magnetic brush and total extension of the array of printing apertures in said printhead structure is also dependent upon the actual distance of said magnetic brush from said printhead structure.

Preferably, a magnetic brush fulfilling the equations above, has a curvature, expressed as a radius, R, (mm) of a circle that best fits to said curvature of said magnetic brush (103) in the development zone (111), wherein $R \geqq 10$ mm

Moreover, it was found that the magnetic brush, with relatively large diameter, as used in electrophotographic devices such as the P400 printer, a commercial product of Agfa Gevaert N.V. or the DCP1-engine, a commercial product of Xeikon N.V., was not at all an ideal solution for the DEP-engine. Good printing quality was observed, when the geometry of the individual magnetic poles in the magnetic brush used in said DEP-device fulfilled the relation IV :

$$N \geqq 0.02D \text{ or } N/D \geqq 0.02 \qquad \text{IV}$$

wherein N denotes the number of magnetic poles, rounded to the next higher integer and D is the perimeter (expressed in mm) of said magnetic brush (in case said magnetic brush is a cilinder then $D = 2\pi R$). N is preferably larger than 0.05D or N/D is larger than 0.05 and most preferably N is larger than 0.1D or N/D is larger than 0.1.

In said magnetic brush, the most important part is the part located in the development zone (111) with surface 112 in the development zone. It was found that the quality of the printing is largely determined by the number of magnetic poles per unit length of said magnetic brush in development zone 111 and thus under surface 112. Good printing quality can be obtained, when the number of magnetic poles (M) situated in that quarter of the core, immediately adjacent to said development zone 111, the middle of wich is situated in the middle of the surface (112) of the sleeve (103b) in development zone 111, is related to the total number of magnetic poles (N) comprised in the magnetic brush. For good printing quality, it is preferred that $M/N \geqq 0.30$.

In other words, it is preferred that at least 30 % of all magnetic poles present are located in that quarter of the core (103a) under the middle of the surface of the magnetic brush (112) delimiting the development zone 111. In fig 3 the quarter of the core (103a) of the magnetic brush (103) immediatly underneath development zone 111, is denoted as 113 and the middle of this quarter by the point Y. In the same figure the middle of the surface (112) of the sleeve (103b) of the magnetic brush is denoted by the point X. The number M, is the number of magnetic poles present in the quarter of the core where X and Y coincide.

Finally the external magnetic field, measured at the outer surface of said sleeve of said magnetic brush, and extending along the distance B, is peferably larger than 0.015 T (Tesla), more preferably more than 0.05 T, and most preferably more than 0.1 T. It is clear that if this magnetic field strength is chosen high enough, carrier loss can be minimized to a large extent. However, increasing the field strength also increases the cost of the apparatus. For that reason an optimum between the actual number of poles and the intrinsic field strength of the individual magnets has to be chosen.

Depending upon the application for which the printing engine according to the DEP-technique as described above has to be used, the printhead structure is fabricated in such a way as to impose the smallest possible implication upon the size and cost of the magnetic brush used in the toner application module. In e.g. a printing device with high printing speed of full color images at medium spatial resolution but high density resolution, it is advisable to use a magnetic brush with small curvature in the development zone combined with a printhead structure with many rows of apertures, each of said apertures having a rather large diameter. In a printing device with a high spatial resolution but a low density resolution it is advisable to use a low-cost magnetic brush with a small diameter and small amount of magnetic poles, combined with a printhead structure comprising only a small amount of rows of apertures, each of said apertures having a small diameter.

The printhead structure used in a preferred embodiment of the present invention is made in such a way that reproducible printing is possible without clogging and with accurate control of printing density. Such a printhead structure has been described in European patent application 94203764.9 filed on December 1994, which is incorporated by reference.

Description of the DEP device

A non limitative example of a device for implementing a DEP method using toner particles according to the present invention comprises (fig 1):

(i) a toner delivery means (101), comprising a container for developer (102) and a magnetic brush (103), this magnetic brush forming a toner cloud (104)
(ii) a back electrode (105)
(iii) a printhead structure (106), made from a plastic insulating film, coated on both sides with a metallic film. The printhead structure (106) comprises one continuous electrode surface, hereinafter called "shield electrode" (106b) facing in the shown embodiment the toner delivering means and a complex addressable electrode structure, hereinafter called "control electrode" (106a) around printing apertures (107), facing, in the shown embodiment, the toner-receiving member in said DEP device. Said printing apertures are arranged in an array structure for which the total number of rows can be chosen according to the field of application. The location and/or form of the shield electrode (106b) and the control electrode (106a) can, in other embodiments of a device for a DEP method using toner particles according to the present invention, be different from the location shown in fig. 1.
(iv) conveyer means (108) to convey an image receptive member (109) for said toner between said printhead structure and said back electrode in the direction indicated by arrow A.

(v) means for fixing (110) said toner onto said image receptive member.

Although in fig. 1 an embodiment of a device for a DEP method using two electrodes (106a and 106b) on printhead 106 is shown, it is possible to implement a DEP method, using toner particles according to the present invention using devices with different constructions of the printhead (106). It is, e.g. possible to implement a DEP method with a device having a printhead comprising only one electrode structure aswell as with a device having a printhead comprising more than two electrode structures. The apertures in these printhead structures can have a constant diameter, or can have a broader entrance or exit diameter. The back electrode (105) of this DEP device can also be made to cooperate with the printhead structure, said back electrode being constructed from different styli or wires that are galvanically isolated and connected to a voltage source as disclosed in e.g. US-P 4,568,955 and US-P 4,733,256. The back electrode, cooperating with the printhead structure, can also comprise one or more flexible PCB's (Printed Circuit Board).

Between said printhead structure (106) and the magnetic brush (103) as well as between the control electrode around the apertures (107) and the back electrode (105) behind the toner receiving member (109) as well as on the single electrode surface or between the plural electrode surfaces of said printhead structure (106) different electrical fields are applied. In the specific embodiment of a device, useful for a DEP method, using a printing device with a geometry according to the present invention, shown in fig 1. voltage V1 is applied to the sleeve of the magnetic brush 103, voltage V2 to the shield electrode 106b, voltages $V3_0$ up to $V3_n$ for the control electrode (106a). The value of V3 is selected, according to the modulation of the image forming signals, between the values $V3_0$ and $V3_n$, on a timebasis or gray-level basis. Voltage V4 is applied to the back electrode behind the toner receiving member. In other embodiments of the present invention multiple voltages $V2_0$ to $V2_n$ and/or $V4_0$ to $V4_n$ can be used.

In a DEP device according to a preferred embodiment of the present invention, said toner delivery means 101 creates a layer of multi-component developer (e.g. a two-component developer, comprising carrier and toner particles wherein the toner particles are triboelectrically charged by the contact with carrier particles or 1.5 component developers, wherein the toner particles get tribo-electrically charged not only by contact with carrier particles, but also by contact between the toner particles themselves) on a magnetic brush 103, and the toner cloud 104 is directly extracted from said magnetic brush 103. In other systems known in the art, the toner is first applied to a conveyer belt and transported on this belt in the vicinity of the apertures.

A device according to the present invention is also operative with a mono-component developer or toner, which is transported in the vicinity of the apertures 107, via a conveyer for charged toner. Such a conveyer can be a moving belt or a fixed belt. The latter comprises an electrode structure generating a corresponding electrostatic travelling wave pattern for moving the toner particles. Also when using a conveyer belt, the curvature of said belt has a maximum curvature, depending on the extension of the array of printing apertures measured in the direction of the movement of receiving substrate and the distance between said conveying belt and the printhead structure.

The magnetic brush 103 preferentially used in a DEP device according to an embodiment of the present invention is of the type with stationary core and rotating sleeve.

In a DEP device, according to the present invention, any type of known carrier particles and toner particles can succesfully be used. It is however preferred to use "soft" magnetic carrier particles. Soft" magnetic carrier particles useful in a DEP device according to the present invention are soft ferrite carrier particles. Such soft ferrite particles exhibit only a small amount of remanent behaviour, characterised in coercivity values ranging from about 50 up to 250 Oe. Further very useful soft magnetic carrier particles, for use in a DEP device according to the present invention, are composite carrier particles, comprising a resin binder and a mixture of two magnetites having a different particle size as described in EP-B 289 663. The particle size of both magnetites will vary between 0.05 and 3 µm. The carrier particles have preferably an average volume diameter (d_{v50}) between 10 and 300 µm, preferably between 20 and 100 µm. More detailed descriptions of carrier particles, as mentioned above, can be found in European patent application 94201026.5, filed on April 14th, 1994, and titled "A method and device for direct electrostatic printing (DEP)", that is incorporated herein by reference.

It is preferred to use in a DEP device according to the present invention, toner particles with an absolute average charge (|q|) corresponding to $1\ fC \leq |q| \leq 20\ fC$, preferably to $1\ fC \leq |q| \leq 10\ fC$. Moreover it is preferred that the charge distribution is narrow, i.e. shows a distribution wherein the coefficient of variability (ν), i.e. the ratio of the standard deviation to the average value, is equal to or lower than 0.33. Preferably the toner particles used in a device according to the present invention have an average volume diameter (d_{v50}) between 1 and 20 µm, more preferably between 3 and 15 µm. More detailed descriptions of toner particles, as mentioned above, can be found in European patent application 94201026.5, filed on April 14th, 1994, and titled "A method and device for direct electrostatic printing (DEP)", that is incorporated herein by reference.

A DEP device making use of the above mentioned marking toner particles can be addressed in a way that enables it to give black and white. It can thus be operated in a "binary way", useful for black and white text and graphics and useful for classical bilevel halftoning to render continuous tone images.

A DEP device according to the present invention is especially suited for rendering an image with a plurality of gray levels. Gray level printing can be controlled by either an amplitude modulation of the voltage V3 applied on the control electrode 106a or by a time modulation of V3. By changing the duty cycle of the time modulation at a specific frequency, it is possible to print accurately fine differences in gray levels. It is also possible to control the gray level printing by a combination of an amplitude modulation and a time modulation of the voltage V3, applied on the control electrode.

The combination of a high spatial resolution and of the multiple gray level capabilities typical for DEP, opens the way for multilevel halftoning techniques, such as e.g. described in the European patent application number 94201875.5 filed on June 29, 1994 with title "Screening method for a rendering device having restricted density resolution". This enables the DEP device, according to the present invention, to render high quality images.

EXAMPLES

Throughout the printing examples, the same developer, comprising toner and carrier particles was used.

The carrier particles

A macroscopic "soft" ferrite carrier consisting of a MgZn-ferrite with average particle size 50 µm, a magnetisation at saturation of 29 emu/g was provided with a 1 µm thick acrylic coating. The material showed virtually no remanence.

The toner particles

The toner used for the experiment had the following composition : 97 parts of a co-polyester resin of fumaric acid and bispropoxylated bisphenol A, having an acid value of 18 and volume resistivity of 5.1×10^{16} ohm.cm was melt-blended for 30 minutes at 110° C in a laboratory kneader with 3 parts of Cu-phthalocyanine pigment (Colour Index PB 15:3). A resistivity decreasing substance - having the following formula : $(CH_3)_3N^+C_{16}H_{33}\ Br^-$ was added in a quantity of 0.5 % with respect to the binder, as described in WO 94/027192. It was found that - by mixing with 5 % of said ammonium salt - the volume resistivity of the applied binder resin was lowered to 5×10^{14} Ω.cm. This proves a high resistivity decreasing capacity (reduction factor : 100).

After cooling, the solidified mass was pulverized and milled using an ALPINE Fliessbettgegenstrahlmühle type 100AFG (tradename) and further classified using an ALPINE multiplex zig-zag classifier type 100MZR (tradename). The average particle size was measured by Coulter Counter model Multisizer (tradename), was found to be 6.3 µm by number and 8.2 µm by volume. In order to improve the flowability of the toner mass, the toner particles were mixed with 0.5 % of hydrophobic colloidal silica particles (BET-value 130 m^2/g).

The developer

An electrostatographic developer was prepared by mixing said mixture of toner particles and colloidal silica in a 4 % ratio (w/w) with carrier particles. The triboelectric charging of the toner-carrier mixture was performed by mixing said mixture in a standard tumbling set-up for 10 min. The developer mixture was run in the development unit (magnetic brush) for 5 minutes, after which the toner was sampled and the tribo-electric properties were measured, according to a method as described in the above mentioned European application 94201026.5, filed on April 14, 1994. The average charge, q, of the toner particles was -7.1 fC.

Measurement of printing quality

A printout made with a DEP device and developer described above, was judged for homogeneity of the image density. The results are given in table 1. In this table the data are summarized according to the following ranking :

1: unacceptable: different rows of apertures are not giving any density at all.
2: poor: toner particles are passing through all printing apertures but some of said rows of apertures have such a small density value that correction of said low-density printing apertures by applying a different voltage to said control electrodes in said rows of apertures does not yield an homogeneous image density.
3: acceptable: the overall image density can be tuned to be homogeneous by changing the voltage applied to some control electrodes of some printing apertures, but the overall printing speed is lowered considerably.
4: good: only small corrections have to be performed for some of the control electrodes in order to become a homogeneous image density.
5: excellent: an homogeneous image density is obtained without any minor changes to the control electrodes of any printing aperture.

The relevant parameters of the printing engines, used in each of the examples, are summarized in table 1.

In table 2, the printing quality of each of the examples is shown together with the figures, showing how well R fulfils the equations I,II and III.

EXAMPLE 1 (E1)

The printhead structure (106)

A printhead structure 106 was made from a polyimide film of 50 µm thickness, double sided coated with a 17 µm thick copperfilm. On the back side of the printhead structure, facing the receiving member substrate, a ring shaped control electrode 106a was arranged around each aperture. Each of said control electrodes was individually addressable from a high voltage power supply. On the front side of the printhead structure, facing the toner delivery means, a common shield electrode (106b) was present. The printhead structure 106 had six rows of apertures. The apertures had an aperture diameter of 200 µm. The width of the copper ring electrodes was 175 µm The rows of apertures were staggered to obtain an overall resolution of 200 dpi. The total extension of the array of said apertures in said printhead structure as defined above (C) was 3.25 mm.

For the fabrication process of the printhead structure, conventional methods of copper etching and mechanical drilling were used, as known to those skilled in the art.

The toner delivery means (101)

The toner delivery means 101 comprised a cylindrical, stationary core/rotating sleeve type magnetic brush (103) comprising two mixing rods and one metering roller. One rod was used to transport the developer through the unit, the other one to mix toner with developer.

The magnetic brush 103 was constituted of the so called magnetic roller, which in this case contained inside the roller assembly a stationary magnetic core, having nine magnetic poles with an open position (no magnetic poles present) to enable used developer to fall off from the magnetic roller (open position was one quarter of the perimeter and located at the position opposite to development zone 111).
The total number of magnetic poles N was 9.
The perimeter of the magnetic brush D was 66.0 mm
The ratio of total number of magnetic poles to the perimeter of the magnetic brush was N/D = 0.136
In the quarter of the perimeter of the magnetic brush, whose middle is in the middle of surface 112 of said magnetic brush, M magnetic poles were present, M being 33 % of the total number of magnetic poles.
The magnetic roller contained also a sleeve, fitting around said stationary magnetic core, and giving to the magnetic brush an overall diameter of 21 mm. The radius R (expressed in mm) of a circle that best fits to the curvature of said magnetic brush (103) in the development zone (111) was thus 10,5 mm.
The sleeve was made of stainless steel roughened with a fine grain to assist in transport (Ra=3 µm) and showed an external magnetic field strength in the developing nip of 0.045 T, measured at the outer surface of the sleeve of the magnetic brush.

A scraper blade was used to force developer to leave the magnetic roller. On the other side a doctoring blade was used to meter a small amount of developer onto the surface of said magnetic brush. The sleeve was rotating at 100 rpm, the internal elements rotating at such a speed as to conform to a good internal transport within the development unit. The magnetic brush 103 was connected to an AC power supply with a square wave oscillating field of 600 V at a frequency of 3.0 kHz with 0 V DC-offset.

The printing engine

The distance B between the front side of the printhead structure 106 and the sleeve (reference surface) of the magnetic brush 103, was set at 350 µm. The distance between the back electrode 105 and the back side of the printhead structure 106 (i.e. control electrodes 106a) was set to 150 µm and the paper travelled at 1 cm/sec. The shield electrode 106b was grounded : V2 = 0 V. To the individual control electrodes an (imagewise) voltage V3 between 0 V and -300 V was applied. The back electrode 105 was connected to a high voltage power supply of +400 V. To the sleeve of the magnetic brush an AC voltage of 600 V at 3.0 kHz was applied, without DC offset.

EXAMPLE 2 (E2)

In example 2 a print was made with the same printhead configuration and magnetic brush as described in example 1, but the distance of said magnetic brush towards said printhead structure was set to 500 µm.

COMPARATIVE EXAMPLE 1 (CE1)

In comparative example 1 the same magnetic brush as described in example 1 was used, but for the printhead structure, an eight-rowed-array of printing apertures was used (same aperture diameter, copper-ring diameter and staggering). The extension of said array of printing apertures as defined above was 4.55 mm. The distance of said magnetic brush towards said printhead structure was set to 350 µm.

EXAMPLE 3 (E3)

In example 3 the same magnetic brush as described in example 1 was used, but for the printhead structure, a four-rowed-array of printing apertures was used (same aperture diameter, copper-ring diameter and staggering). The extension of said array of printing apertures as defined above was 1.95 mm. The distance of said magnetic brush towards said printhead structure was set to 500 µm.

EXAMPLE 4 (E4)

In example 4 the same magnetic brush as described in example 1 was used, but for the printhead structure, a compact design was chosen. The printhead structure was formed of 2 rows of apertures, said apertures having a square form of 200 by 200 µm, a square copper electrode of 50 µm around each aperture, said 2 rows of apertures isolated from each other by a 100 µm broad isolation zone. This printhead structure had a resolution of 127 dpi and was fabricated using the technique of plasma etching. The extension of said array of printing apertures in said printhead structure was only 0.4 mm. The distance of said magnetic brush towards said printhead structure was set to 350 µm.

EXAMPLE 5 (E5)

In example 5 a printhead structure having a four-rowed-array of printing apertures was used (200 µm aperture diameter, copper-ring diameter of 550 µm and staggered to obtain an overall resolution of 127 dpi). The extension of said array of printing apertures as defined above was 1.95 mm.
The magnetic brush used consisted of 6 magnetic poles divided over half of the perimeter of an internal drum on the side facing the apertured printhead, and had a sleeve with outer diameter of 63 mm and a surface roughness of 3.5 µm (Ra). This magnetic brush was characterised by N/D=0.03 , M/N=0.50 and showed an external magnetic field strength (at the outer surface of the sleeve) extending over distance B of 0.05 T. The distance of said magnetic brush towards said printhead structure was set to 400 µm.

EXAMPLE 6 (E6)

In example 6 the same magnetic brush as described in example 5 was used. The printhead structure used, however, was one with eight rows of printing apertures with the same design parameters as described in example 5 but with an extension of said array of printing apertures of 4.55 mm. The distance of the magnetic brush towards said printhead structure was 400 µm.

COMPARATIVE EXAMPLE 2 (CE2)

In comparative example 2 the same printhead structure as described in example 6 was used, but the magnetic brush consisted of only 3 magnetic poles divided over half of the perimeter of an internal drum on the side facing the printhead structure, and had a sleeve with outer diameter of 63 mm and a surface roughness of 3.5 µm (Ra). This magnetic brush was characterised by N/D=0.015 , M/N=0.33 and showed an external magnetic field strength (measured at the outer surface of the sleeve) extending over the distance B of 0.04 T. The distance of said magnetic brush towards said printhead structure was set to 400 µm. Printing examples with good quality could not be obtained by this magnetic brush. As a main problem, carrier loss was observed at the zone between two of said magnetic poles, resulting in a not-well-behaved magnetic brush. By increasing the distance between said magnetic brush and said printhead structure, the problem could be solved, but the resultant density was lowered very considerably.

EXAMPLE 7 (E7)

In example 7 the same printhead structure as described in example 6 was used, but the magnetic brush consisted of 14 magnetic poles divided over two thirds of the perimeter of an internal drum on the side facing the apertured printhead, and had a sleeve with outer diameter of 63 mm and a surface roughness of 3.5 µm (Ra). This magnetic brush was characterised by N/D=0.071 , M/N=0.36 and showed an external magnetic field strength (at the outer surface of the sleeve) extending over distance B of 0.02 T. The distance of said magnetic brush towards said printhead structure was set to 400 µm. Printing examples with good quality could be obtained by this magnetic brush. As compared to comparative example 2 the magnetic field strength at the surface of said brush was smaller, but as the number of poles is much higher, no problem of carrier loss was observed.

EXAMPLE 8 (E8)

In example 8 a printhead structure was used, having 8 rows of printing apertures, each aperture having a diameter of 300 µm, and a copper electrode ring with a width of 200 µm. Each row of apertures was further separated from each other by an additional isolating zone of 200 µm. As printhead substrate a 125 µm thick PI-foil was used. The 8 rows of printing apertures were staggered to obtain an overall printing resolution of 100 dpi. The extension of said array of printing apertures in said printhead structure was 6.30 mm. The magnetic brush as described in example 7 was used. The magnetic brush was placed at 400 µm from said printhead structure.

EXAMPLE 9 (E9)

In example 9 the same experiment was performed as in example 8, but with the magnetic brush placed at 700 µm from said printhead structure.

EXAMPLE 10

In example 10 the same printhead structure as described in examples 6 and 7 was used, but the magnetic brush consisted of 15 magnetic poles divided over 60% of the perimeter of an internal drum on the side facing the apertured printhead, and had a sleeve with outer diameter of 42 mm and a surface roughness of 3.0 µm (Ra). This magnetic brush was characterised by N/D=0.11 , M/N=0.40 and showed an external magnetic field strength (at the outer surface of the sleeve) extending over distance B, of 0.100 T. The distance of said magnetic brush towards said printhead structure was set to 500 µm.

TABLE 1

Example	R*	B**	C***	N/D†	M/N††	T†††
E1	10.5	0.35	3.25	0.136	0.33	0.045
E2	10.5	0.50	3.25	0.136	0.33	0.045
CE1	10.5	0.35	4.55	0.136	0.33	0.045
E3	10.5	0.50	1.95	0.136	0.33	0.045
E4	10.5	0.35	0.40	0.136	0.33	0.045
E5	31.5	0.40	1.95	0.032	0.50	0.050
E6	31.5	0.40	4.55	0.032	0.50	0.050
CE2	31.5	0.40	4.55	0.015	0.33	0.040
E7	31.5	0.40	4.55	0.071	0.36	0.020
E8	31.5	0.40	6.30	0.071	0.36	0.020
E9	31.5	0.70	6.30	0.071	0.36	0.020
E10	21	0.50	4.55	0.114	0.40	0.100

* R is the radius (expressed in mm) of the circle that best fits to the curvature of the magnetic brush (103) in the development zone (111).
** B is the distance in mm, between the reference surface of the magnetic brush and the printhead structure.
*** C is the extension in mm of said array of printing apertures (107) in the direction of the movement of said receiving substrate (109).
† N/D is the total number N of magnetic poles present in the magnetic brush, divided by the perimeter D of the magnetic brush.
†† M/N is the number of magnetic poles present in that quarter of the perimeter of the magnetic brush, whose middle is in the middle of surface 112 of said magnetic brush divided by the total number of magnetic poles.
††† T is the value of the magnetic field extending over distance B and measured at the outer surface of the sleeve of the magnetic brush, in T (Tesla).

TABLE 2

Example	R_{min} Equa. I	R_{min} Equa. II	R_{min} Equa. III	R_{real}	Quality
E1	6.08	13.13	29.75	10.5	3
E2	4.45	10.30	26.47	10.5	4
CE1	11.92	26.12	58.32	10.5	1
E3	1.60	3.71	9.51	10.5	5
E4	0.09	0.20	0.45	10.5	5
E5	1.95	4.37	10.28	10.5	5
E6	10.62	23.80	55.95	31.5	4
CE2	10.62	23.80	55.95	31.5	1
E7	10.62	23.80	55.95	31.5	4
E8	20.35	45.62	107.27	31.5	3
E9	12.31	29.73	86.28	31.5	4
E10	8.72	20.20	51.76	21	4

In tabel 2, columns 1 to 3 the minimal radius, R, necessary for good printing, calculated according to equation I, II and III respectively, using the values of B and C from table 1, is reported. Column 4 gives the real R corresponding with the magnetic brush that was used. The values reported in this column are taken from the second column of table 1. In column 5, the printing quality is given in values from 1 to 5, 5 being the highest quality.

From table 2 it is clear that the best results are obtained when the radius, R, fulfils even equation III. When R fulfils no equation at all, the printing quality is very bad, see CE1.

Claims

1. A DEP device that comprises :

a back electrode (105),
a printhead structure (106), at the front side of the receiving substrate (109),
an array of printing apertures (107) in said printhead structure (106) through which a particle flow can be electrically modulated by a control electrode (106a),
a toner delivery means (101), comprising a magnetic brush (103), comprising toner particles and magnetically attractible carrier particles, the reference surface of said magnetic brush being placed at a distance B (in mm) from the front of said printhead structure (106b), facing said magnetic brush, characterised in that

(i) a magnetic field is formed over said distance B
(ii) said magnetic brush has a curvature in the development zone fulfilling the equation I :

$$R \geqq \frac{C^2}{4.25B + 0.25} \qquad \text{I}$$

wherein
the curvature R of said magnetic brush in the development zone is expressed as the radius (in mm) of a circle that best fits to said curvature of said magnetic brush in the development zone and C is the extension (in mm) of the array of printing apertures (107) in the direction of the movement of said receiving substrate (109) measured from the middle of the apertures in the first row to the middle of the apertures in the last row.

2. A device according to claim 1, wherein said radius R fulfils the equation II :

$$R \geqq \frac{C^2}{1.55B + 0.25} \qquad \text{II}$$

3. A device according to claim 1, wherein said radius R fulfils the equation III :

$$R \geqq \frac{C^2}{0.30B + 0.25} \qquad \text{III}$$

4. A device according to any of claims 1 to 3, wherein said magnetic brush is characterised by the relation:

$$N \geqq 0.02D$$

wherein N denotes the total number of magnetic poles (rounded to the next higher integer) in said magnetic brush and D denotes the perimeter length of said brush in mm.

5. A device according to any one of the preceding claims, wherein the number M of magnetic poles in the quarter (113) of the perimeter of the core (103a) of said magnetic brush (103), whose middle is in the middle of surface (112) of the sleeve (103b) of said magnetic brush in development zone (111) is related to said total number, N, of the magnetic poles present in said magnetic brush as $M/N \geqq 0.3$.

6. A device according to any of the preceding claims, wherein at said surface 112 of said magnetic brush a magnetic field of at least 0.02 T (Tesla) is present.

7. A device according to any one of the preceding claims, wherein said magnetic brush is cylindrical and has a radius $R > 10$ mm.

8. A device according to any one of the preceding claims, wherein said printing apertures 107 are square.

9. A device according to any of the preceding claims, wherein said toner particles have an average charge ($|q|$), in absolute value, fulfilling the equation $1 \text{ fC} \leqq |q| \leqq 20 \text{ fC}$.

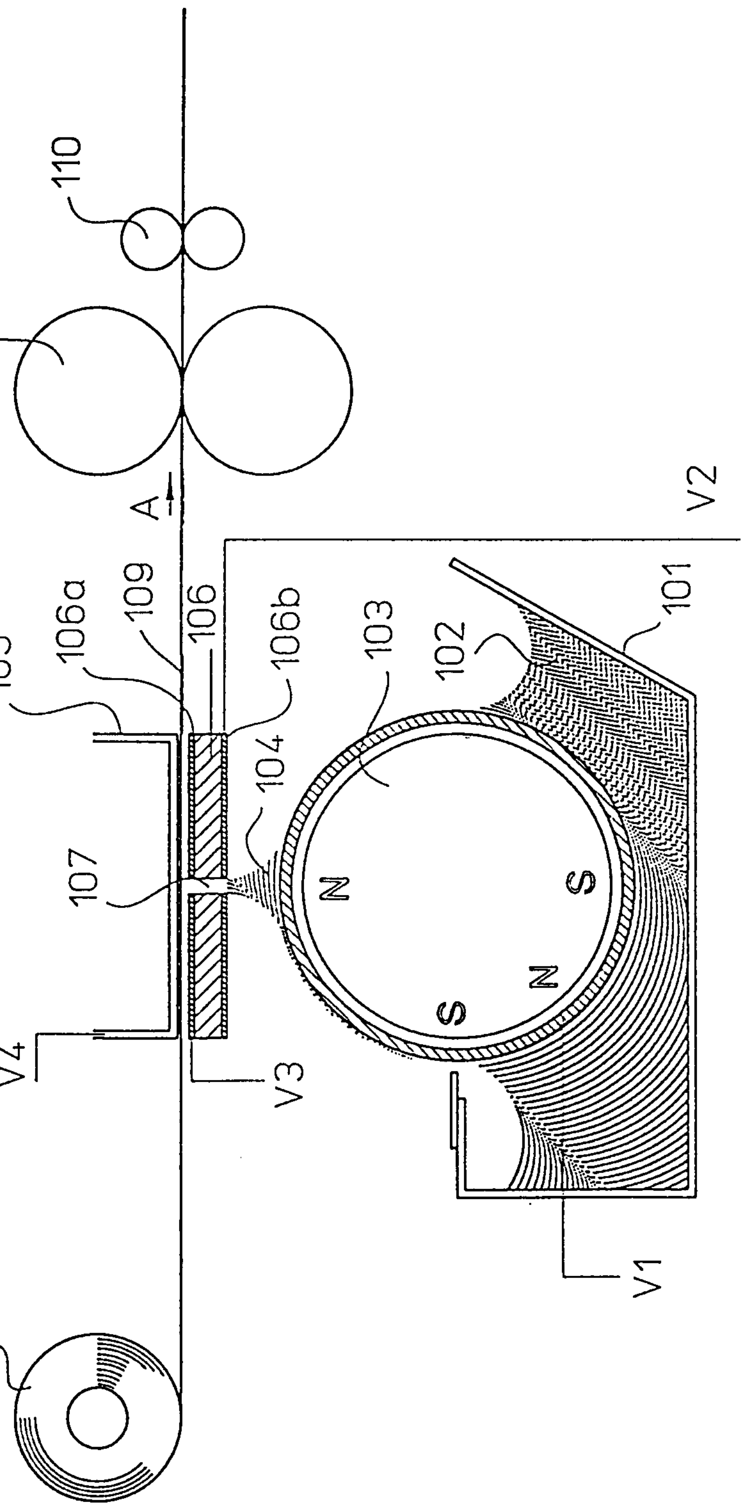
108
110
108
A
V2
106a
109
106
106b
103
102
101
105
104
107
N
S
N
S
V4
V3
V1

Fig.1

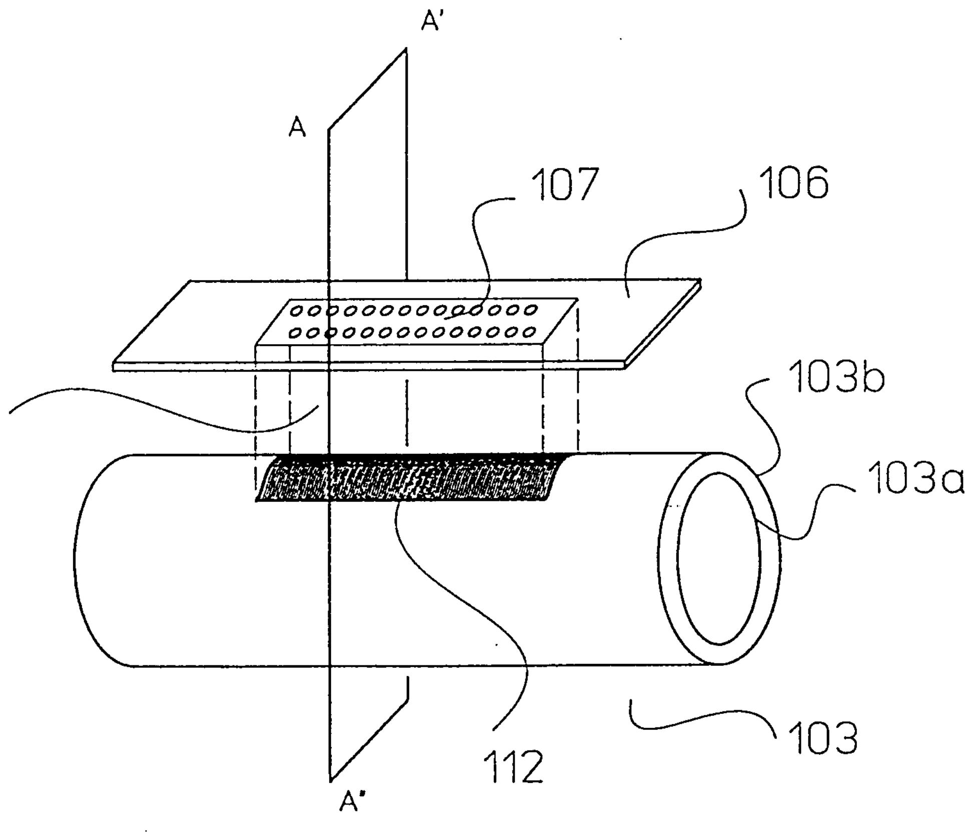

Fig. 2

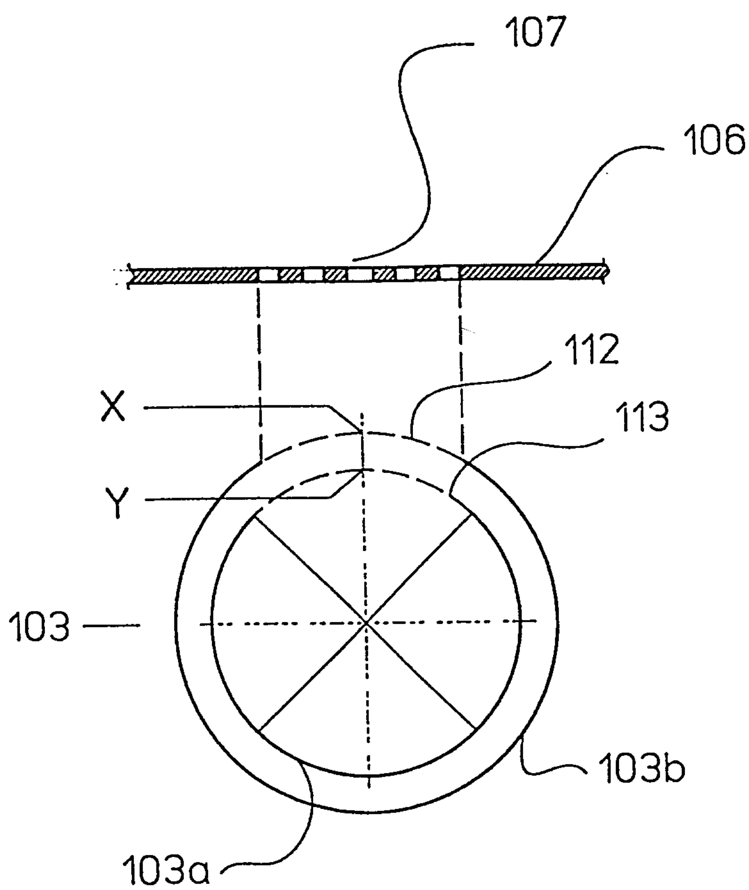

Fig. 3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 20 0556

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	PATENT ABSTRACTS OF JAPAN vol. 007 no. 202 (P-221) ,7 September 1983 & JP-A-58 100153 (CANON KK) 14 June 1983, * abstract * ---	1	G03G15/34
A	PATENT ABSTRACTS OF JAPAN vol. 009 no. 308 (P-410) ,4 December 1985 & JP-A-60 140279 (HITACHI SEISAKUSHO KK) 25 July 1985, * abstract * ---	1	
D,A	US-A-5 327 169 (THOMPSON MICHAEL D) 5 July 1994 * abstract; figure 1 * -----	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			G03G

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	7 August 1995	Cigoj, P

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