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(54) A method of printing in a device for direct electrostatic printing comprising a printhead structure with deflection electrodes and a means for electrically controlling said deflection electrodes

(57) A printhead structure (106) for use in a device for direct electrostatic printing with an addressability AD in dots per cm, is provided comprising a sheet of insulating material (106c) having a first and a second face, at least one row of printing elements (116) on said substrate, each of said printing elements including at least one printing aperture (107) through said insulating substrate. The printhead structure further comprises at least one set of deflection electrodes arranged in said printhead structure so as to have at most one deflection electrode near two adjacent printing elements. The deflection electrodes are coupled to a voltage source for applying to each set of deflection electrodes a varying voltage. Preferably the number of printing elements per cm, in the row of printing elements, is equal to the addressability, AD, and the varying voltage has a frequency, f, correlated to the line time of the printing LT, so that $f \times LT \geq 1.00$.

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Description

FIELD OF THE INVENTION

[0001] This invention relates to a recording method and an apparatus for use in the process of Direct Electrostatic Printing (DEP), in which an image is created upon a receiving substrate by creating a flow of toner particles from a toner bearing surface to the image receiving substrate and image-wise modulating the flow of toner particles by means of an electronically addressable printhead structure.

BACKGROUND OF THE INVENTION

[0002] In DEP (Direct Electrostatic Printing) toner particles are deposited directly in an image-wise way on a receiving substrate, the latter not bearing any image-wise latent electrostatic image.
[0003] 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, or from electrophotography in which an additional step and additional member is introduced to create the latent electrostatic image (photoconductor and charging/exposure cycle).
[0004] A DEP device is disclosed in e.g. **US-A-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.

[0005] Each control electrode is formed around one aperture and is isolated from each other control electrode.
[0006] Selected electric 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 support for a toner receiving substrate 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 substrate, interposed in the modulated particle stream. The receiving substrate is transported in a direction perpendicular to the printhead structure, to provide a line-by-line scan printing. The shield electrode may face the toner delivery means and the control electrodes may face the receiving substrate. A DC-field is applied between the printhead structure and a single back electrode on the receiving substrate. This propulsion field is responsible for the attraction of toner to the receiving substrate that is placed between the printhead structure and the back electrode.
[0007] One of the recognised problems with this type of printhead structures is that the printing apertures focus the toner flux on the receiver leading to lower density spaces in the printing direction between neighbouring printing apertures, and drastically reducing the maximum density that can be obtained with such printhead structures.
[0008] Several possible solutions for this problem of lower density lines in the print direction have been described.
[0009] In **US-A-4 860 036** e.g. a printhead structure with at least 3 rows of printing apertures is disclosed in order to diminish the white zone between neighbouring printing apertures.
[0010] In **US-A-5 666 148** and **US-A-5 714 992** said problem is tackled by the implementation of a printhead structure that comprises control electrodes with more than one aperture per control electrode.
[0011] In **US-A-5 659 344** a DEP device is disclosed having a printhead structure that comprises an insulating material with apertures and control electrodes, and extra apertures in between two of said neighbouring control electrodes.
[0012] In **EP-A-780 740** a printhead structure, for a DEP device is disclosed that comprises an insulating material and a slit as printing aperture with many control electrodes reaching to the end of said slit aperture. In such a printhead structure lower density banding in the print direction is impossible. However, the construction of said slit-printhead structure is not that easy.
[0013] In **US-A-5 625 392** an edge electrode is described so that instead of individual apertures or a larger slit as described in **EP-A-780 740** an even larger free zone between the toner applicator and the receiver exists, resulting in even density printing without lower density banding. Moreover, it is much easier to manufacture such a DEP device comprising an edge electrode.
[0014] In **DE-A-195 34 705** a DEP device is described in which the problem of lower density banding is tackled by the introduction of two different printhead structures and two toner application devices. This is of course an easy but costly solution to said banding problem.

[0015] Further interesting concepts for diminishing said problem of lower density banding have been proposed. In **US-A-5 170 185** a DEP device is disclosed that comprises a printhead structure, an ultrasonic vibration means, an image information generating means and a toner deflecting means. Said toner deflecting means is a set of deflection electrodes (isolated from said control electrodes) positioned in between said image receptive member and said printhead structure. Between said two sets of deflection electrodes a varying electrical field is applied resulting to deformation of said toner flux towards said image receptive member. In this disclosure said varying electrical field can be a pulsed voltage, a stepwise voltage as well as a saw-tooth voltage. The printhead structure is rather complex since it comprises (if it is formed in a PCB-layout) three different conductor layers that have to be isolated from each other. If a simple printhead structure is used with only two planes with electrodes, a further set of deflection electrodes is placed between the printhead structure and the substrate to be printed.

[0016] The same idea has also been proposed in **US-A-5 606 402**, where a DEP device is disclosed which comprises a layer of control electrodes in a control grid, a toner flying stabilisation grid and a set of deflection electrodes that can position a dot on the final receiver on one of different possible positions.

[0017] In **WO-97 35 725** a DEP device and a method of printing have been described comprising at least a set of deflection electrodes and a controller for said deflection electrodes so that through one printing aperture three dots can be printed, in a straight, a left and a right position. In such a case the number of control electrodes is lower than the addressability of the device. I.e. there are less control electrodes than dots printed. This implementation can enhance the resolution of the printhead structure or diminish the complexity by reducing the number of control IC's that are essential for providing the image variation, but by using said deflection electrodes on a time-based scale to print three different dots on the receiving material in consecutive order, the maximum attainable printing speed is diminished by a factor of at least 3.

[0018] In **DE-A-197 39 988** and its US equivalent **US-A-5,774,159** a DEP device and a method of printing have been described comprising at least a set of deflection electrodes and a controller for said deflection electrodes. On the control electrodes a changing voltage is applied with a period equal to the line time. Thus during line time the toner flow trough a printing aperture is continuously moved from one side to another so that a circular dot is printed as an ellipse. By doing so white banding in the print direction is avoided. As shown in that disclosure (figure 10) the white banding is avoided in the higher density, but is not totally avoided in the lower densities.

[0019] All these prior art implementations do, at least partially, cope with the problem of lower density banding but mostly at the cost of machine complexity or printing speed, moreover in all prior art disclosures the deflection is implemented using printhead structures having two electrodes between adjacent printing apertures. Thus there is still a need for further improved DEP devices making it possible to print at elevated speed with no or very low lower density banding in areas of maximum density and comprising a printhead structure that can easily be manufactured.

OBJECTS AND SUMMARY OF THE INVENTION

[0020] It is an object of the invention to provide a printhead structure for use in a DEP device, that can easily be manufactured at fairly low cost and that can be used with a wide variety of types of toner particles, and that can print at high speed with low clogging of the printing apertures, with high maximum density without lower density banding and with a printing quality that is constant over a long period of time.

[0021] It is a further object of the invention is to provide a DEP device, i.e. a device for direct electrostatic printing that can print at high speed with low clogging of the printing apertures and with high and constant maximum density with almost no white banding parallel to the printing direction.

[0022] It is an other object of the invention to provide a method for direct electrostatic printing with dry toner particles making it possible to print patches of even density with very low unevenness and almost no white striping parallel to the printing direction even in low density areas.

[0023] Further objects and advantages of the invention will become clear from the detailed description herein after. The first object of the invention is realised by providing a printhead structure (106) for use in a device for direct electrostatic printing with an addressability, AD, in dots per cm, comprising :

- an insulating substrate (106c) with a first and a second face
- at least one row of printing elements (116) on said substrate, each of said printing elements including at least one printing aperture (107) through said insulating substrate, and
- at least one set of deflection electrodes (106b1, 106b2), arranged in said printhead structure

characterised in that
said at least one set of deflection electrodes are arranged so as to have at most one deflection electrode near two adjacent printing elements of said at least one row.

[0024] Preferably in said row of printing elements a number per cm of printing elements is present equal to said addressability, AD. The second object of the invention is realised by providing a device for direct electrostatic printing with an addressability, AD, in dots per cm and a line time, LT, comprising

- a means for delivering charged toner particles, said means having a surface bearing charged toner particles (112) coupled to a means for applying a first electric potential (DC1) to said surface,
- a means for coupling an image receiving substrate (108) to a second electric potential (DC4) different from said first, said difference (|DC4-DC1|) creating an electric field between said surface and said substrate, wherein a flow of said charged toner particles (104) towards said substrate is created,
- a means (115) for moving said substrate in a printing direction (arrow A) so as to have a line time, LT,
- a printhead structure (106), placed between said toner bearing surface (112) and said image receiving substrate (108), leaving a gap, d, between said toner bearing surface and said printhead structure and leaving a gap, d_B, between said printhead structure and said image receiving substrate,

  said printhead structure having

  a sheet of insulating material (106c) with a first and a second face, at least one row of printing elements (116) on said substrate, each of said printing elements including at least one printing aperture (107) through said insulating substrate,
  at least one set of deflection electrodes (106b1, 106b2), so as to have, near two adjacent printing elements , at most one deflection electrode

  - a voltage source, DC3, coupled to said printing elements for image-wise applying electric potentials (V3) to said printing elements for selectively opening and closing said printing apertures in accordance with image data and
  - a voltage source, coupled to said at least one set of deflection electrodes, for applying a varying voltage to said deflection electrodes.

[0025] Preferably in said row of printing elements a number per cm of printing elements is present equal to said addressability, AD and said voltage source applies a varying voltage with a frequency, f, relates to the line time, LT, such that $f \times LT \geq 1.00$.

[0026] The third object of the invention is realised by providing a method for direct electrostatic printing with an addressability AD in dots per cm, on an image receiving substrate comprising the steps of :

- applying a potential difference (|DC4-DC1|) between a surface carrying charged toner particles and said image receiving substrate for creating a flow of said charged toner particles from said surface to said substrate,
- placing, in said flow of charged toner particles, a printhead structure having

  an insulating substrate (106c) with a first and a second face and
  a at least one row of printing elements (116) on said substrate, each of said printing elements including at least one printing aperture (107) through said insulating substrate,
  at least one set of deflection electrodes (106b1, 106b2), said set of deflection electrodes being arranged in said printhead structure so as to have, near two adjacent printing elements, at most one deflection electrode,

- moving said substrate with respect to said printhead structure in a printing direction (arrow A), so as to have a line time of LT,
- sending a print signal to a voltage source DC3 for image-wise applying electric potentials (V3) to said printing elements for selectively opening and closing said printing apertures in accordance with image data and
- coupling said deflection electrodes to a voltage source for applying a varying voltage to said deflection electrodes.

[0027] Preferably in said row of printing elements a number per cm of printing elements is present equal to said addressability, AD and said voltage source applies a varying voltage with a frequency, f, such that $f \times LT \geq 1.00$.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028]

Figure 1 shows schematically a printhead structure according to the prior art.
Figure 2 shows schematically a first implementation of the first embodiment of a printhead structure useful in a

method for Direct Electrostatic Printing and in a DEP device according to of the present invention.

Figure 3 shows schematically a second implementation of the first embodiment of a printhead structure useful in a method for Direct Electrostatic Printing and in a DEP device according to of the present invention.

Figure 4 shows schematically a third implementation of the first embodiment of a printhead structure useful in a method for Direct Electrostatic Printing and in a DEP device according to of the present invention.

Figure 5 shows schematically a first implementation of the second embodiment of a printhead structure useful in a method for Direct Electrostatic Printing and in a DEP device according to of the present invention.

Figure 6 shows schematically a second implementation of the second embodiment of a printhead structure useful in a method for Direct Electrostatic Printing and in a DEP device according to of the present invention.

Figure 7 shows a DEP device comprising a printhead structure according to the first possible embodiment of a printhead structure useful in a method for Direct Electrostatic Printing and in a DEP device according to of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Definitions

[0029]

Line time (LT): the time for printing one pixel dot. When an aperture is kept open during the total line time, maximum density is achieved in that one pixel dot. When, e.g., a pixel with a dimension of 250 μm in the print direction A is printed in a printer running at 200 cm/min, the line time, LT, is 8 ms.

Write time (WRT): a fraction of LT. By changing WRT grey scale printing is effected. When e.g., LT is divided in 128 parts, and WRT varies between 0/128 LT to 128/128 LT.

Wait time (WAT): $LT - WRT = WAT$.

Addressability: the number of dots printed per unit of length (25.4 dots per inch (dpi) equal 1 dot per cm) that are addressed. Thus a DEP device having a number of control electrodes equal to the addressability have one control electrode for each dot to be addressed. One dot can be written via one printing aperture controlled by one control electrode or by more than one printing aperture when these printing apertures are controlled by one control electrode. The latter system has been described in detail in e.g. EP-A-754 557.

Printing element : In this document, one or more printing apertures together with the part of a single control electrode near to that printing aperture(s) is designated by the wording "printing element". E.g., referring to figure 3a of this text, printing aperture 107 and conductor C1 of control electrode 106a together form a printing element 116.

Adjacent printing elements : for this document adjacent printing elements are printing elements that are adjacent in a row of printing elements. These can, but must not, be printing elements arranged in the printhead structure to print adjacent dots on the image receiving member.

[0030] It is known in the art of DEP (direct electrostatic printing), as described in the background art section above, that printing is performed by jetting dry toner particles through an aperture in a printhead structure to an image receptive member, leading to image density which is highest in the centre of said aperture and diminishes to the edge of the apertures. This is advantageous for printing high resolution lines, but when printing patches of even density, this phenomenon leads easily to lower density stripes (further on called "white stripes") parallel to the printing direction resulting in areas of even density. This banding phenomenon is easily perceptible for the human eye and is judged as bad image quality.

[0031] In direct electrostatic printing charged toner particles are moved in a continuous flow in an electric field from a surface bearing toner particles to a substrate and a printhead structure with printing apertures associated with control electrode is positioned in that flow. By image-wise applying different voltages to the control electrodes around the printing apertures, the amount of toner particles that pass through a printing aperture and/or the time wherein toner particles can pass through a specific apertures is image-wise modulated.

[0032] It has been disclosed in e.g. **US-A-5 170 185**, **US-A-5 606 402**, **WO-97 35 725** and in **US-A-5,774,159** to provide deflection electrodes with a varying voltage to smear the dot over a larger area than would be printed without the use of deflection electrodes and deflection voltages. Especially in US-A-5,774,159 a DEP printing system giving good printing quality, both in terms of resolution and absence of lower density banding, is disclosed.) However in all prior art disclosures the deflection is implemented by placing extra electrodes at some distance of the printhead structure or by placing at least two sets of deflection electrodes on the printhead structure in such a way that between two adjacent printing apertures at least two deflection electrodes are present, one of each set. In figure 1, a prior art printhead structure is shown having two rows of printing apertures (107), each of the printing apertures being surrounded by a control electrode that is connected to a voltage source (DC3). Between the printing apertures, in the same plane as the control electrodes, two sets of deflection electrodes (106b1 and 106b2) connected to voltage source V1 and V2 respectively) are present. By adjusting V1, V2 and DC3 it is possible to deflect the toner flow so that through one printing aperture three dots can be printed, in a straight, a left and a right position perpendicular to the printing direction (arrow A). In this case the number of control electrodes is 1/3 of the addressability of the printing device, since for printing 3 dots, only one control electrode is necessary. The printing speed of such a device is lowered (in this case three times) with respect to printing devices wherein the number of control electrodes equals the addressability.

[0033] It is also possible to couple these deflection electrodes, as e.g. in US-A-5,774,159, to a voltage source for providing a varying voltage with a frequency, f, so that f x LT is exactly 1.00. Thus during the line time, LT, when the varying voltage is applied to the deflection electrodes, the flow of toner particles through the printing aperture moves from one side to the other side of said printing aperture in a direction perpendicular to the printing direction. Thus helps to avoid the occurrence of white stripes in the print direction.

[0034] The printhead structures of the prior art are all implemented with two deflection electrodes between two adjacent printing elements.

[0035] It was now found that the beneficial effect described in the prior art could be realised by using a printhead structure wherein near or between two adjacent printing elements of a row, at most one deflection electrode was present. This clearly simplifies the construction of the printhead structure and gives the possibility to diminish the pitch in the row of printing apertures since only one deflection electrode has to pass between the adjacent printing elements.

[0036] Thus this invention encompasses a printhead structure (106) for use in a device for direct electrostatic printing with an addressability, AD, in dots per cm , comprising :

- an insulating substrate (106c) with a first and a second face
- at least one row of printing elements (116) on said substrate, each of said printing elements including at least one printing aperture (107) through said insulating substrate, and
- at least one set of deflection electrodes (106b1, 106b2),

characterised in that
said at least one set of deflection electrodes is arranged so as to have at most one deflection electrode extending between two adjacent printing elements.

[0037] A printhead structure according to this invention, wherein only one deflection electrode is present near or between two adjacent printing elements, can be manufactured in two embodiments. In a first embodiment, the deflection electrode passing between the printing elements can originate from two (or more) sets of deflection electrodes and the deflection electrode between a first printing element and a second originates from the first set, the deflection electrode between said second printing element and a third, adjacent to said second, originates from the second set, the deflection electrode between said third printing element and a fourth, adjacent to said third, originates again from the first set, and so on.
In a second embodiment only one set of deflection electrodes is present and the deflection electrodes between the printing elements originate from said only one set.

First embodiment of a printhead structure according to this invention

[0038] In fig. 2a, 2b and 2c the first and second face and a cross section along line A-A of a first implementation of the first embodiment of a printhead structure according to this invention is shown. The printhead structure comprises an insulating material and conductors in only two planes. Figure 2a shows the control electrodes (106a) on the first face of the insulating material, rectangular printing apertures (107) with three conductors, C1 around the apertures, a conductor C3 and a conductor C2 coupled to a voltage source (DC3) that in accordance with image-data changes the electric field in the printing aperture, the conductor C1 and the printing aperture 107 associated with each of them, form printing element (116). Figure 2b shows the second face of the insulating material (106c) with a shield electrode is shown in a form so as to be useful as deflection electrode (further on such shield electrode will be termed 'deflection electrode').It shows two sets of deflection electrodes, each of said sets formed as a comb. The first set, as shown, looks like first comb (106b1), the teeth of which extend to the row of printing elements (116) and the second set as a second comb (106b2), the teeth of which extend also to the row of printing elements. Thus the teeth of the comb are basically parallel with the printing direction. The teeth of the first comb alternate with the teeth of the second comb. In a cross section along line A-A', through the centre of the printing elements of the row of printing elements, as shown in figure 2c the sequence of printing elements and deflection electrodes is thus: a deflection electrode from the second set, a printing element, a deflection electrode of the first set, a printing element, a deflection electrode from the second set, and so on. The centre of each printing aperture, which coincides in this embodiment with the centre of the printing element, is located in the middle between the teeth surrounding it, thus the teeth are symmetrically positioned with respect to the centre of the printing elements.

[0039] In Fig. 3a, 3b and 3c a second implementation of the first embodiment of a printhead structure according the present invention, is shown. Basically the printhead structure is construed as the one shown in figures 2a, 2b and 2c, except that now two parallel rows of staggered printing elements are present each of them coupled to a voltage source (DC3) that in accordance with image-data changes the electric field in the printing aperture on the first side of the insulating material as shown in figure 3a. As shown in figure 3b two sets of deflection electrodes (106b1, 106b2) are formed on the second side of the insulating material (106c) in the form of two combs the teeth of which are not rectilinear and that pass between the two rows of printing elements. Again, the centre of each printing element is located in the middle between the teeth surrounding it. In figure 3c a cross-section along the line A-A, through the printing apertures and the electrodes on one row is shown. On one face of the insulating material control electrodes (106a) are present around each of the printing apertures (107)on the other face deflection electrodes are present between two printing apertures one deflection electrode are present, one (106b1)of the first set, then one (106b2) of the second set.

[0040] In Fig. 4a, 4b and 4c a third implementation of the first embodiment of a printhead structure according to the present invention, is shown. Basically the printhead structure is construed as the one shown in figures 3a, 3b and 3c, except for the fact that only half the number of deflection electrodes is present. In figure 4c, a cross-section through line A-A is shown, wherein the following sequence is shown : a deflection electrode of the second set, a printing element, a printing element, a deflection electrode of the second set, and so on.

[0041] Although it is preferred that the teeth of the first comb alternate with the teeth of the second comb, this is not necessary so, a printhead structure wherein these teeth do not alternate regularly is within the scope of this invention as long as between two printing apertures one deflection electrodes from different sets are present.

The second embodiment of a printhead structure of this invention.

[0042] In the second embodiment of a printhead structure of this invention, only one set of deflection electrodes is present.

[0043] The single set of deflection electrodes is arranged in such a way that the deflection electrodes are asymmetrically positioned with respect to the printing apertures and that only one deflection electrode is near or between two adjacent printing elements.

[0044] In Fig. 5a, 5b and 5c a printhead structure according to a second embodiment of the present invention, is shown. It comprises, as shown in figure 5a, on the first side of an insulating support two rows of printing elements (116), wherein a control electrode (106a) is associated with at least one aperture (107) coupled to a voltage source (DC3) that in accordance with image-data changes the electric field in the printing aperture and as shown in figure 5b, a single set of deflection electrodes (106b) on the second side of the insulating material (106c), shown in the form of a ladder with two beams and rungs therebetween placed in such a way that each printing element is located between two of said rungs. The centre of each printing element (116) is located off the middle between the teeth surrounding it. The cross-section along line A-A, shown in figure 5c, gives the following sequence : a deflection electrode, a printing element, a deflection electrode, a printing element, and so on. Although this asymmetrical location of the printing apertures is a preferred embodiment, it is possible to locate the centre of the apertures in the middle between the teeth. Although in fig. 5b the single set of deflection electrodes is shown as a ladder with two beams and rungs therebetween placed in such a way that each printing aperture is located between two of said rungs it is possible to construct the single set of deflection electrodes as a single comb like structure wherein the teeth of the comb extend until near the printing apertures in the row of printing apertures.

[0045] Figure 6 shows a printhead structure according to a second implementation of the second embodiment of the present invention, wherein four parallel rows of printing elements are shown in figure 6a at one face of the insulating material, each printing element having a control electrode (106a) controlling two apertures (107) and a single set of deflection electrodes on the other side of said isolating material, shown in figure 6b,, said single set of deflection electrodes being positioned in a non-symmetrical way in between two neighbouring printing apertures in a single row of printing apertures. In this figure the single set of deflection electrodes is shown as a ladder with two beams and rungs therebetween placed in such a way that each printing aperture is located between two of said rungs. It is clear that also in this implementation of a printhead structure useful in this invention, the single set of deflection electrodes could be made comb shaped.

[0046] The insulating material, used for producing a printhead structure according to the present invention, (both according to first and second embodiment) can be glass, ceramic, plastic, etc. Preferably said insulating material is a plastic material, and can be a polyimide, a polyester (e.g. polyethylelene terephthalate, polyethylene naphthalate, etc.), polyolefines, an epoxy resin, an organosilicon resin, rubber, etc.

[0047] The selection of an insulating material for the production of a printhead structure according to the present invention, is governed by the elasticity modulus of the insulating material. Insulating material, useful in the present invention, has an elasticity modulus between 0.1 and 10 GPa, both limits included, preferably between 2 and 8 GPa and most preferably between 4 and 6 Gpa. The insulating material has a thickness between 25 and 1000 µm, preferably between 50 and 200 μm.

[0048] Both in the first and in the second embodiment of a printhead structure of the invention it is possible to have the control electrodes and the deflection electrodes on the same face of the insulating material or to have the control electrodes on a first face of the insulating material and two sets of deflection electrodes on the other side. In the latter case it is advantageous to provide deflection electrodes with a thickness between 5 and 200 μm, even more advantageous to provide deflection electrodes with a thickness between 10 and 100 μm, both limits included. By doing so it is possible to incorporate the printhead structure in a DEP device in such a way that the deflection electrodes are in contact with the toner bearing surface and thus keep the distance between said surface and the printhead structure constant. In this case it is possible to dispense with additional spacing means for keeping the distance between the toner bearing surface and the printhead structure constant.

[0049] Printhead structures according to this invention having at least one set of deflection electrodes as described above can be used in any DEP device known in the art, e.g. in devices as described in EP-A-795 802, EP-A-780 740, EP-A-740 224, EP-A-731 394, EP-A-712 055, US-A-5 606 402, US-A-5 523 777, GB-A-2 108 432, US-A-4 743 926. It can also be used in a method for direct electrostatic printing operating without back electrode, as disclosed in EP-A-823 676. Also in a method and device for direct electrostatic printing wherein the toner bearing surface is the sleeve of a magnetic brush with a rotating core, as described in EP-A-827 046 a printhead structure according to this invention can be useful.

[0050] The invention thus includes a device for direct electrostatic printing, for direct electrostatic printing with an addressability, AD, in dots per cm, comprising :

- a means for delivering charged toner particles, said means having a surface bearing charged toner particles (112) coupled to a means for applying a first electric potential (DC1) to said surface,
- a means for coupling an image receiving substrate (108) to a second electric potential (DC4) different from said first, said difference (|DC4-DC1|) creating an electric field between said surface and said substrate, wherein a flow of said charged toner particles (104) towards said substrate is created,
- a means (115) for moving said substrate in a printing direction (arrow A) so as to have a line time, LT,
- a printhead structure (106), placed between said toner bearing surface (112) and said image receiving substrate (108), leaving a gap, d, between said toner bearing surface and said printhead structure and leaving a gap, d_B, between said printhead structure and said image receiving substrate, said printhead structure having

  a sheet of insulating material (106c) with a first and a second face, at least one row of printing elements (116) on said substrate, each of said printing elements including at least one printing aperture (107) through said insulating substrate,

  at least one set of deflection electrodes (106b1, 106b2), arranged in said printhead structure so as to have, near two adjacent printing elements, at most one deflection electrode

- a voltage source, DC3, coupled to said printing elements for image-wise applying electric potentials (V3) to said printing elements for selectively opening and closing said printing apertures in accordance with image data and
- a voltage source, coupled to said at least one set of deflection electrodes, for applying a varying voltage to said deflection electrodes.

[0051] The voltage source coupled to said deflection electrodes can be equipped for providing a stepwise varying voltage to the deflection electrodes. I.e. the voltage applied to the deflection electrodes varies in discrete steps. By doing so de DEP device of this invention can be used for printing multiple dots through one printing, since the step wise varying voltage applied to the deflection electrode deflects the toner to discrete places on the imaging substrate. The voltage source can, e.g., be designed to apply a voltage varying in three steps to the deflection electrodes, in a first step the left deflection electrode is given an attracting voltage so that the toner particles are, during printing, deviated to the left side of the centre of the printing element, then no deflection voltage is used and the toner particles are attracted at the centre of the printing elements and then the right deflection electrode is given an attracting voltage so that the toner particles are, during printing, deviated to the right side of the centre of the printing element. Ways and means for applying a voltage varying in discrete steps to deflection electrodes has been described in e.g. US-A-5 847 733 or it equivalent WO-Å-97 35725. In this case the number of control electrodes in the printhead can be diminished to 1/3 of the addressability of the printing device, since for printing 3 dots, only one printing element (one control electrode) is necessary or the addressability increased with a factor three for a given number of printing elements per cm. The printing speed is however diminished by a factor 3.

[0052] The voltage source coupled to said deflection electrodes can be equipped for providing a continuously varying voltage to the deflection electrodes.

[0053] In a DEP device according to this invention including a printhead structure wherein at most one deflection electrode is present between the printing elements, the deflection electrodes can also beneficially be used for deflecting the toner flow continuously during the line time so that an elliptic dot would be formed through a circular-shaped aperture, said long side of said elliptic dot being positioned essentially perpendicular to said printing direction. This diminishes the occurrence of white stripes in the print direction.

[0054] When the voltage source coupled to the at least one set of deflection electrodes (whatever embodiment of the printhead structure is used) is equipped for providing a continuously varying voltage, is highly preferred that the number of printing elements per cm in the row(s) of printing elements equals the addressability of the printer. Thus this invention encompasses a DEP device including printhead structure with at most one deflection electrode is near or between the printing elements and including a voltage source equipped for providing a continuously varying voltage with a frequency, f, such that $f \times LT \geq 1.00$ to said deflection electrodes. Preferably the voltage source is arranged for providing a continuously varying voltage with a frequency, f, such that $f \times LT \geq 2.00$. Even more preferably the voltage source is arranged for providing a continuously varying voltage with a frequency so that $f \times LT \geq 4.00$.

[0055] Preferably the frequency, f, of said varying voltage is equal to or larger than 125 Hz.

[0056] Although it may be useful, for diminishing the occurrence of white stripes to chose f so that a product f x LT that is not an integer value, it is preferred that the varying voltage is preferably synchronous with the line time, i.e. the application of the varying voltage to the sets of deflection electrodes starts when the printing starts, i.e. at the beginning of the line time, and ends when the printing ends, i.e. at the end of the line time. Thus the product f x LT is preferably chosen so that it is an integer value.. However, when the product is chosen so as not to be an integer, said product of f x LT should not be too close to an integer value because otherwise moiré effect at a low (i.e. visible) frequency can occur. Using a product of, e.g. $f \times LT = 1.25$ gives an acceptable result, whereas using a product of $f \times LT = 1.05$ for the same printhead structure, does give lower image quality than using a product that is exactly an integer.

[0057] When a DEP device according to this invention includes a printhead structure according to the first embodiment (two sets of deflection electrodes and only one deflection electrode near or between adjacent printing elements) that is coupled to a continuously varying voltage for avoiding white stripes in the print direction, each set of deflection electrodes is coupled to a voltage source that applies a varying voltage to said set of deflection electrodes, i.e. set one is coupled to a voltage source providing a varying voltage, AC5 and the second set to a voltage source providing a varying voltage, AC6. It is preferred that the frequencies and the peak-to-peak voltage of AC5 and AC6 are equal. It is further preferred that the voltage signals, AC5 and AC6 are 180 ° out of phase so that the peak-to-peak voltage is in this case the sum of the peak-to-peak voltages of both signals, then the effect on the avoidance of lower density banding in the print direction is maximised. In this case the sum of the peak-to-peak voltages of AC5 and AC6 (i.e. AC5 + AC6) is equal to or larger than 300 V.

[0058] When in a DEP device of this invention a printhead structure according to the second embodiment (one set of deflection electrodes and only one deflection electrode near or between adjacent printing elements) is used, the set of deflection electrodes is preferably coupled to a voltage source delivering a varying voltage applied to the deflection electrodes has preferably a peak-to-peak voltage equal to or larger than 300 V, more preferably equal to or larger than 500 V.

[0059] The continuously varying voltages provided by the voltage source coupled to the deflection electrodes vary on a time scale the toner flux passing an aperture is, during the line time moved from left to right so that an elliptic dot would be formed through a circular-shaped aperture, said long side of said elliptic dot being positioned essentially perpendicular to said printing direction. Thus when using DEP device according to this invention with continuously varying voltages on the deflection electrode, only one pixel is formed by one control electrode (controlling one or more printing apertures), but by using a continuously varying voltage on the deflection electrodes, the pixel is kind of "smeared" in a direction essentially perpendicular to the printing direction, so that lower density banding in the print direction is avoided.

[0060] The voltage source for providing the continuously varying voltage, that is coupled to the deflection electrodes may be equipped to provide a varying voltage with different shapes. Various shapes of varying voltage signals can be used in the present invention: e.g. pulsed signals, stepwise signals, saw-tooth signals, sinusoidal signals, etc., as long as the signal has a frequency, f, fulfilling one of the conditions above.

[0061] If so desired, the voltage source for providing the continuously varying voltage, that is coupled to the deflection electrodes may further be equipped to provide a DC-offset (DC-bias) on the deflection electrodes, which can be beneficial for adjusting the density in the printed image. The varying voltage can the vary symmetrically around the DC-offset as well as asymmetrically.

[0062] In fig. 7 a DEP device incorporating a printhead structure according to this invention is shown.

[0063] The DEP device shown comprises means for delivering toner particles with a container (101) for non magnetic mono component developer, a roller (112) having a surface on which toner particles are applied by means of a feeding roller (111) made of porous foamed polymers, a developer mixing blade (114) mixing and transporting said non-magnetic mono-component developer towards said feeding roller, a doctor blade (113) regulating the thickness of the charged toner particles upon the surface of said roller (112), i.e. on the toner bearing surface. Said roller (112) bearing said charged toner particles rotates in a direction depicted by arrow B. A device for applying a DC voltage is connected to the sleeve of said roller (112) and applies voltage DC1 to said sleeve and a device for applying an AC-field is connected to the sleeve of said roller and applies AC-field AC1 to said sleeve (the toner bearing surface).

[0064] The device, as shown, further comprises a back electrode (105) connected to a DC voltage source applying a voltage DC4 to the electrode. An image receiving substrate (108) is passed by means for moving (115) the substrate in the direction of arrow A between a printhead structure according to this invention and the back electrode by conveying means (115). The difference between DC4 and DC1 applies a DC propulsion field wherein a flow of toner particles (104) is created from the sleeve of the roller bearing charged toner particles to the image receiving substrate on the back electrode. The AC-field - AC1 - on the sleeve of the toner roller (112) makes the flow (104)of toner particles denser than when no AC-field would be present.

[0065] A printhead structure (106) is placed in said flow (104) of toner particles, said printhead structure having an insulating material (106c) carrying control electrodes (106a) and deflection electrodes (106b1 and 106b2). A DC-source (DC3) is connected to the control electrodes and the voltage applied by this DC-source is image-wise modulated in order to modulate the toner flow image wise in the vicinity of the control electrodes. The voltage applied by the DC source DC3 can be varied between a value totally blocking the passage of the toner particles, and a value leaving the toner flow pass totally unimpeded. The control electrodes in said printhead structure are placed at a distance, d, in µm from the toner bearing surface, a spacer (110) keeps the distance d constant during operation of the device. The printhead structure (106) is placed at a distance, d_B, form the image receiving member.

[0066] The sets of control electrodes (106b1 and 106b2) are connected to voltage sources for providing a varying voltage (AC5 and AC6) on said sets of deflection electrodes. The varying voltages have the sane frequency, f, such that $f \times LT \geq 1.00$.

[0067] The device comprises further means (109) for fixing the toner particles to the image receiving substrate.

[0068] Said means for coupling an image receiving substrate (108) to a second electric potential (DC4) can be a back electrode placed directly behind the image receiving substrate. In this case, the substrate can be in contact with the back electrode or so close to the back electrode that both the back electrode and the image receiving substrate assume essentially the same electric potential. Said means for coupling an image receiving substrate (108) to a second electric potential (DC4) can also be a conductive layer present, on the image receiving substrate, that is coupled to a voltage source. Such DEP devices and methods have been described in e.g. EP-A-823 676 or European Application 98201302 filed on April 22 1998.

[0069] The distance d_B is in devices operating with a back electrode calculated from the surface of the printhead structure to the surface of the image receiving substrate.

[0070] When in a DEP device a printhead structure according to this invention is incorporated with the control electrodes on a first face of the insulating material and the set of deflection electrodes on the other side, it is advantageous to provide deflection electrodes with a thickness between 1 and 200 µm. Preferably the deflection electrodes are , in that case between 5 and 200 µm thick. It proved even more advantageous to provide deflection electrodes with a thickness between 10 and 100 µm, both limits included. By doing so it is possible to incorporate the printhead structure in a DEP device in such a way that the deflection electrodes are in contact with the toner bearing surface and thus keep the distance between said surface and the printhead structure constant. In this case it is possible to dispense with additional spacing means (110) for keeping the distance between the toner bearing surface and the printhead structure constant.

[0071] The back electrode (105) of a DEP device can also be made to co-operate with the printhead structure according to this invention, 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-A- 4**, **568,955** and **US-A-4, 733, 256**. The back electrode, co-operating with the printhead structure, can also comprise one or more flexible PCB's (Printed Circuit Board).

[0072] In a DEP device incorporating a printhead structure according to this invention, wherein only one deflection electrode is present near or between two adjacent printing elements, it is preferred that the distance d_B in µm relates to the propulsion field, PF, between the toner bearing surface and the imaging substrate (this is the absolute value of the difference in voltage between DC4 and DC1) (in V) in a ratio, R1, so that $R1 = (PF/d_B) \leq 1.5\ V/\mu m$, preferably so that $R1 = (PF/d_B)/d_B \leq 1.0\ V/\mu m$. The difference are taken in their absolute value, since the sign of the difference is chosen depending on the sign of the charge (positive of negative) of the toner particles, thus $PF = (|DC4-DC1|)$.

[0073] It was found that the printing quality in a DEP device incorporating a printhead structure according to this invention, wherein only one deflection electrode is present near or between two adjacent printing elements, was improved when said ratio R1 related to the peak voltage (V_p) applied to the set or sets deflection electrodes by the voltage source coupled to said set. When a continuously varying voltage is applied to said set or sets of deflection electrodes, it was found that for good printing quality the peak-to-peak voltage of voltage AC5 and AC6 relates to the ratio $R1 = (|DC4-DC1|)/d_B$ as $V_p/R1 > 250\ \mu m$, preferably $V_p/R1 > 400\ \mu m$ wherein $V_p = AC5 + AC6$

[0074] The present invention incorporates also a method for Direct Electrostatic Printing using a DEP device incorporating a printhead structure according to this invention. It thus includes a method for direct electrostatic printing with an addressability AD in dots per cm, on an image receiving substrate comprising the steps of :

- applying a potential difference (|DC4-DC1|) between a surface carrying charged toner particles and said image receiving substrate for creating a flow of said charged toner particles from said surface to said substrate,
- placing, in said flow of charged toner particles, a printhead structure having

  an insulating substrate (106c) with a first and a second face and
  a at least one row of printing elements (116) on said substrate, each of said printing elements including at least one printing aperture (107) through said insulating substrate,
  at least one set of deflection electrodes (106b1, 106b2), said set of deflection electrodes being arranged in said printhead structure, near two adjacent printing elements, at most one deflection electrode,

- moving said substrate with respect to said printhead structure in printing direction A, so as to have a line time of LT,
- sending a print signal to DC-voltage source DC3 for image-wise applying electric potentials (V3) to said printing elements for selectively opening and closing said printing apertures in accordance with image data and image-wise depositing toner particles on said substrate, and
- coupling said deflection electrodes to a voltage source for applying a varying voltage to said deflection electrodes. Preferably said printhead structure has a number of printing elements per cm, measured in a direction essentially perpendicular to the printing direction, equal to the addressability, AD and the voltage source is equipped for applying a continuously varying voltage with, a frequency, f, such that $f \times LT \geq 1.00$.

[0075] Preferably said frequency, f, is chosen so that $f \times LT \geq 2.00$ and more preferably so that $f \times LT \geq 4.00$.

[0076] When the method of this invention is used for grey scale printing is, it is possible to determine - for each line to be printed - the printing element necessitating the shortest write time of all printing elements in that line and to adapt the frequency, f, of the voltage coupled to the deflection electrodes to that shortest write time, WRT_{short}, so has to have $f \times WRT_{short} = 1.00$. This leads, e.g., with a line time, LT, of 8 ms for a shortest write time, WRT_{short}, of 1/10 LT to a frequency of 1250 Hz. This can be done with the proviso that the frequency is not higher than 4000 Hz.

[0077] For grey scale printing,, the time of application of the potentials by voltage source DC3 may be image-wise modulated while applying a constant potential (i.e. time modulation of the image signal or pulse-width-modulation) or the potential itself may be image-wise modulation at a constant line-time (amplitude modulation) or the amplitude modulation can be combined with a time modulation, the latter combination allowing for the printing of a large number of grey levels. Then using time modulation (either alone or in combination with amplitude modulation) the write time (WRT) for low density areas is smaller than the total line time (LT). The line time (LT) is divided into several smaller time units (called sub-lines (SL). The grey scale printing proceeds by having DC-source DC3 to provide a voltage V_{30} (voltage allowing maximum density to be printed) at the control electrode 106a during a certain number of said smaller time units (i.e. during the write time (WRT)) and having DC-source DC3 to provide a voltage V3n (blocking voltage giving minimum density) during $LT - WRT = WAT$ (wait time). The above implies that maximum density is printed when $WRT = LT$ and minimum density when WRT = 0. The printing of intermediate densities proceeds at values of WRT between these two extremes.

[0078] When, for writing lower densities, the write time is smaller than the line time it is possible to position the write time at different positions within the line time. It is, e.g., possible to start the write time for the printing elements with WRT < LT together with the write time for the printing elements with $WRT = LT$, thus positioning the shorter write times in the beginning of the line time, or the smaller line times can be positioned exactly in the centre of the line time. E.g. with a line time of 10 ms and a write time of 2 ms, the printing aperture is kept closed (a closing potential is applied to the printing element) during the first 4 ms of the line time, then the printing aperture is opened (an opening potential is applied to the printing element) for 2 ms and is closed for the remaining 4 ins of the line time. This latter positioning has been described in US-A-5,774,159, where the deflection electrodes are coupled to a varying voltage with a frequency, f, so that the product of the frequency with the line time (LT) is exactly one or $f \times LT = 1.00$.

[0079] It was now found that the occurrence of white stripes in the low density areas could be diminished and even avoided, when for grey scale printing using time modulation (alone or in combination with amplitude modulation), the method of this invention was combined with the method disclosed in EP-A-851 316 and the equivalent US serial Number 08/995,778, that is incorporated herein by reference.

[0080] In that disclosure means and ways to place the write time of pixel dots with WRT < LT, within the total line time are described.

[0081] In one embodiment the combination of the method of this invention with the method of EP-A-851 316 is performed by not positioning the write time, when it is smaller than the line time, for every pixel and line at a fixed position within the total line time, but by have it randomly positioned within the line time.

[0082] It proved even more beneficial to have the write time divided in several parts and have these parts divided over the total line time. Thus when an optical density necessitating a write time of, e.g., 0.2 of the line time has to be printed, the white banding was strongly diminished, in a method of this invention, when instead of printing the total write time in consequence the write time was divided in, e.g., 5 portions of 0.04 times the line time and these 5 portions were printed randomly within the line time.

[0083] Thus, in very preferred embodiment of this invention, in the method of this invention the step of sending a print signal for image-wise applying electric potentials to said printing elements can be performed by sending a print signal within a line time, to said printing elements, said print signal comprising elements necessitating a write time shorter than said line time, and by positioning said write time, shorter than said line time, randomly over said line time.

[0084] Thus it is highly preferred, in the method of this invention, that before the step of sending an image signal for image-wise applying electric potentials to said printing elements, said write time, shorter than said line time is divided in portions and said print signal is adapted to send said portion in a random way during said line time.

[0085] The combination of a high spatial resolution and of the multiple grey level capabilities typical for DEP, opens the way for multilevel halftoning techniques, such as e.g. described in EP-A-634 862 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

[0086] After printing, the printing quality, especially with respect to the lower density was visually evaluated on a scale from 1 to 10, wherein 1 is bad, 5 is acceptable and 10 is very good.

[0087] In all printing examples the line time LT was set to 8 ms.

COMPARATIVE PRINTING EXAMPLE 1 (CPE1)

[0088] The printhead structure.

[0089] A printhead structure (106) was made from a polyimide film of 50 μm thickness (106c), double sided coated with a 5 μm thick copper film. The printhead structure (106) had one row of printing apertures. On the front side of the printhead structure, facing the toner bearing roller, a rectangular shaped control electrode (106a) was arranged around each aperture. Each of said control electrodes had conductive paths in a direction parallel to the printing direction over 10 mm and was connected over 2 MΩ resistors to a HV 507 (trade name) high voltage switching IC, commercially available through Supertex, USA, that was powered from a high voltage power amplifier. The printing apertures were rectangular shaped with dimensions of 200 by 100 μm. The dimension of the central part (C1) of the rectangular shaped copper control electrodes was 320 by 300 μm, the line width of the extending segments was 100 μm. The apertures were spaced at a 500 μm pitch. On the back side of the printhead structure, facing the image receiving member, a double set of deflection electrodes (106b1 and 106b2) was arranged in between each set of neighbouring apertures, thus two deflection electrodes were present between adjacent printing elements. Said deflection electrodes had a line width of 70 μm and were isolated from each other by a free zone of 70 μm. The centre of said free zone was located in the middle between two neighbouring printing apertures so that both sets of deflection electrodes were available in a symmetrical order with respect to the printing apertures. Said printhead structure was fabricated in the following way. First of all the control electrode pattern and deflection electrode pattern was etched by conventional copper etching techniques. The apertures were made by a step and repeat focused excimer laser making use of the control electrode patterns as focusing aid. After excimer burning the printhead structure was cleaned by a short isotropic plasma etching cleaning. Finally a thin coating of PLASTIK70, commercially available from Kontakt Chemie, was applied over the control electrode and deflection electrode side of said printhead structure.

[0090] The toner delivery means

[0091] The toner delivery means was a commercially available toner cartridge comprising non magnetic mono component developer, the COLOR LASER TONER CARTRIDGE MAGENTA (M3760GIA), for the COLOR LASER WRITER (Trade names of Apple Computer, USA). The toner bearing surface is the surface of an aluminium roller (112), whereon tone particles are applied by a feeding roller (111) The toner particles carried a negative charge.

[0092] The printing engine

[0093] The printhead structure, mounted in a PVC-frame, was bent with frictional contact over the surface of the roller of the toner delivery means. A 50 μm (this is distance d) thick polyurethane coating was used as self-regulating spacer means (110).

[0094] A back electrode was present behind the paper whereon the printing proceeded, the distance between the back electrode (105) and the back side of the printhead structure (d_B) was set to 1000 μm and the paper travelled at 300 cm/min.

[0095] The back electrode was connected to a high voltage power supply, applying a voltage DC4 of + 1000 V to the back electrode. To the toner bearing surface of the toner delivery means a sinusoidally changing AC voltage (AC1) with

400 V peak to peak and a frequency of 3 kHz was applied and a DC-offset (DC1) of -50 V. The DC-propulsion field, i.e. the potential difference between DC4 and DC1, was 1050 V. To the individual control electrodes an (image-wise-selected) voltage was applied selected from 0 V (printing a pixel of maximum density) or -280 V (printing a pixel of minimum density). To the first set of deflection electrodes a sinusoidally changing AC voltage (AC5) with 250 V peak to peak and a frequency of 500 Hz was applied, to the second set of deflection electrodes a sinusoidally changing AC voltage (AC6) with 250 V peak to peak and a frequency 500 Hz. Said frequency was adjusted so that it was synchronised with said first AC-voltage applied to said first set of deflection electrodes but 180° out of phase: i.e. the voltage applied to said first set of deflection electrodes gained a maximum value (.e.g. +250 V) at the moment that the voltage applied tot said second set of deflection electrodes gained a minimum value (e.g. -250V) was applied. Thus the maximum peak voltage difference between on the sets of deflection electrodes was 500 V, this is V_p.

[0096] Grey scale images of a human face and control wedges from maximum to minimum density were printed during several minutes after which the image quality was observed in terms of lower density stripes in the printing direction in regions of higher image density.

[0097] The results of the evaluation of the printing quality are given in table 1.

PRINTING EXAMPLES 1 (PE1)

[0098] The same experiment was done as described in comparative printing example 1 except that the printhead structure has two sets of deflection electrodes arranged so that only one deflection electrode was present between adjacent printing elements. The amplitude of the synchronised AC5 and AC6, block waves, applied was set to 80 V, (peak to peak value). Thus the maximum peak voltage difference (V_p) between the two sets of deflection electrodes was 160 V. The frequency of AC5 and AC6 was 125 Hz, thus the line time, LT, being 8 ms, f X LT = 1.00 The results of the evaluation of the printing quality are given in table 1.

PRINTING EXAMPLE 2 (PE2)

[0099] The experiment of printing example 1 was repeated, except for the amplitude of the synchronised AC5 and AC6, block waves, applied which was set to 130 V, (peak to peak value). Thus the maximum peak voltage difference (V_p) between the two sets of deflection electrodes was 260 V.

PRINTING EXAMPLE 3 (PE3)

[0100] The experiment of printing example 2 was repeated, except for the amplitude of the synchronised AC5 and AC6, block waves, applied which was set to 180 V, (peak to peak value). Thus the maximum peak voltage difference (V_p) between the two sets of deflection electrodes was 360 V.

PRINTING EXAMPLE 4 (PE4)

[0101] The experiment of printing example 2 was repeated, except for the amplitude of the synchronised AC5 and AC6, block waves, applied which was set to 280 V, (peak to peak value). Thus the maximum peak voltage difference (V_p) between the two sets of deflection electrodes was 560 V.

PRINTING EXAMPLE 5 (PE5)

[0102] The experiment of printing example 2 was repeated, except for the frequency of the synchronised AC5 and AC6, block waves, which was set to 250 Hz.

PRINTING EXAMPLE 6 (PE6)

[0103] The experiment of printing example 5 was repeated, except for the shape of the synchronised AC5 and AC6, which was a saw-tooth.

PRINTING EXAMPLE 7 (PE7)

[0104] The experiment of printing example 2 was repeated, except for the shape of the synchronised AC5 and AC6, which was sinusoidal.

PRINTING EXAMPLE 8 (PE8)

[0105] The same experiment was done as described in example 7 except that the printhead structure had only one set of deflection electrodes as depicted in figure 3. The deflection electrode had a width of 75 µm and was asymmetrically located in between two neighbouring printing apertures (having a pitch of 600 µm) at a distance of 75 µm from one aperture and at a distance of 250 µm from the other printing aperture. Only a single AC-source was used having a sinusoidally changing voltage of 800 V (peak tot peak) at a frequency of 125 Hz.
[0106] The results of the evaluation of the printing quality are given in table 1.

PRINTING EXAMPLES 9 (PE9)

[0107] The same experiment was done as described in example 8 except that the printhead structure had 4 rows of printing apertures as depicted in figure 4. The deflection electrode had a width of 75 µm and was asymmetrically located in between two neighbouring printing apertures (having control electrodes with dual apertures of 100 µm width and 100 µm isolation in between said two apertures in a single control electrode, and each row of printing apertures having a pitch of 800 µm) at a distance of 100 µm from one aperture and at a distance of 325 µm from the other printing aperture. Only a single AC-source was used having a sinusoidally changing voltage of 800 V (peak tot peak) at a frequency of 250 Hz. Very good results were obtained with this printhead structure without any noticeable lower density stripes in the print direction.
[0108] The results of the evaluation of the printing quality are given in table 1.

PRINTING EXAMPLES 10 (PE10)

[0109] The same experiment was done as described in example 9 except that the single AC-source had a sinusoidally changing voltage of 1000 V (peak tot peak) and a frequency of 500 Hz. Very good results were obtained with this printhead structure without any noticeable lower density stripes in the print direction.
[0110] The results of the evaluation of the printing quality are given in table 1.

TABLE 1

#	d_B (µm)	DC4 $^{(V)}$	No	AC5	AC6	f^+ Hz	$R1^{++}$	$V_p/R1$ $	QC£
CPE1	1000	1000	2	250	250	500, s	1.0	500	7
PE1	1000	1000	1	80	80	125, b	1.0	160	5
PE2	1000	1000	1	130	130	125, b	1.0	260	7
PE3	1000	1000	1	180	180	125,b	1.0	360	9
PE4	1000	1000	1	280	280	125, b	1.0	560	10
PE5	1000	1000	1	130	130	250, b	1.0	260	8
PE6	1000	1000	1	130	130	250, sts	1.0	260	9
PE7	1000	1000	1	130	130	250, s	1.0	260	8
PE8	1000	1500	1	800	-	125 s	1.5	533	7
PE9	1000	1500	1	800	-	250 s	1.5	533	8
PE10	1000	1500	1	1000	-	500 s	1.5	666	9

No : number of deflection electrodes between adjacent printing elements
+ frequency and form of the varying voltage : s : sinusoidal, b : block, sts : saw-tooth symmetrical, sta : saw-tooth asymmetrical
++ R1 = DC4/d_B since the value of DC1 was in all experiments small compared to the value of DC4, the difference |DC4-DC1| was taken to be equal to DC4.
$ V_p/R1 equals (AC5+AC6)/(DC4/d_B)
£ QC : printing quality 10 is very good, 1 is bad, 5 is; acceptable.
◊ : deflection electrodes facing the toner bearing substrate and contacting it; in the other examples the deflection electrodes faced the substrate to be printed.

[0111] It must be clear for those skilled in the art that the incorporation of a non-complicated deflection design in a printhead structure for the DEP-technique can solve the problem of lower density stripes in the print direction.

[0112] It is, e.g., also possible to use a stochastic method in the generation of halftone values (as described in EP-A-851 316 in combination with a not-coupled deflection voltage source. It is also possible to incorporate the deflection electrodes in different layers (multilayer structure) and enhancing the deflection voltage in ratio proportional to the isolation power. It is also possible to combine the concept of deflection electrodes with other concepts for elimination of lower density stripes as multiple printhead structures, multiple apertures per control electrode, multipass printing, sliding contact between the toner particle source and the printhead structure, etc..

Claims

1. A printhead structure (106) for use in a device for direct electrostatic printing with an addressability, AD, in dots per cm, comprising :

- an insulating substrate (106c) with a first and a second face
- at least one row of printing elements (116) on said substrate,

    each of said printing elements including at least one printing aperture (107) through said insulating substrate,
    and at least one set of deflection electrodes (106b1, 106b2),

characterised in that
said at least one set of deflection electrodes is arranged so as to have at most one deflection electrode extending between two adjacent printing elements.

2. A printhead structure according to claim 1, wherein only one set of deflection electrodes is present.

3. A printhead structure according to claim 2, wherein said at most one deflection electrode between said adjacent printing elements is located asymmetrically between said printing elements.

4. A printhead structure according to claim 1, wherein two sets of deflection electrodes are present.

5. A printhead structure according to any of claims 1 to 4, wherein control electrodes are present on said first face of said insulating material and said deflection electrodes are present on said second side of said insulating material.

6. A printhead structure according to claim 5, wherein said deflection electrodes have a thickness between 1 and 200 µm.

7. A printhead structure according to claim 5, wherein said deflection electrodes have a thickness between 5 and 200 µm.

8. A printhead structure according to any of claims 1 to 7, wherein said printhead structure has a number of printing elements per cm equal to said addressability, AD.

9. A device for direct electrostatic printing with an addressability, AD, in dots per cm, comprising

- a means for delivering charged toner particles, said means having a surface bearing charged toner particles (112) coupled to a means for applying a first electric potential (DC1) to said surface,
- a means for coupling an image receiving substrate (108) to a second electric potential (DC4) different from said first, said difference (|DC4-DC1|) creating an electric field between said surface and said substrate, wherein a flow of said charged toner particles (104) towards said substrate is created,
- a means (115) for moving said substrate in a printing direction (arrow A) so as to have a line time, LT,
- a printhead structure (106) according to any of claims 1 to 8, placed between said toner bearing surface (112) and said image receiving substrate (108), leaving a gap, d, between said toner bearing surface and said printhead structure and leaving a gap, d_B, between said printhead structure and said image receiving substrate,
- a voltage source, DC3, coupled to said printing elements for image-wise applying electric potentials (V3) to said printing elements for selectively opening and closing said printing apertures in accordance with image data and

- a voltage source, coupled to said at least one set of deflection electrodes, for applying a varying voltage to said deflection electrodes.

10. A device according to claim 9, wherein said voltage source is equipped for providing a voltage varying in discrete steps.

11. A device according to claim 9, wherein said voltage source is equipped for providing a continuously varying voltage with a frequency, f, so that $f \times LT \geq 1.00$.

12. A device according to claim 9, wherein said voltage source is equipped for providing a continuously varying voltage with a frequency, f, so that $f \times LT \geq 2.00$.

13. A device according to any of claims 9 to 12, wherein said distance d_B and said electric potential difference (|DC4-DC1|) relate to each other in a ratio R1 such that $(|DC4\text{-}DC1|)/d_B \leq 1.5\ V/\mu m$.

14. A device according to any of claims 9 to 13, wherein said deflection electrodes are coupled to a voltage source equipped for providing a varying voltage to said deflection electrodes with a peak-to-peak voltage, V_p, so that $V_p/R1 > 250\ \mu m$.

15. A method for direct electrostatic printing with an addressability AD in dots per cm, on an image receiving substrate comprising the steps of :

- applying a potential difference (|DC4-DC1|) between a surface carrying charged toner particles and said image receiving substrate for creating a flow of said charged toner particles from said surface to said substrate,
- placing, in said flow of charged toner particles, a printhead structure according to any of claims 1 to 8,
- moving said substrate with respect to said printhead structure in a printing direction (arrow A), so as to have a line time of LT,
- sending a print signal to a voltage source DC3 for image-wise applying electric potentials (V3) to said printing elements for selectively opening and closing said printing apertures in accordance with image data and
- coupling said deflection electrodes to a voltage source for applying a varying voltage to said deflection electrodes.

16. A method according to claim 15, wherein said voltage source is equipped for providing a voltage varying in discrete steps.

17. A method according to claim 15, wherein said voltage source is equipped for providing a continuously varying voltage with a frequency, f, so that $f \times LT \geq 1.00$.

18. A method according to claim 15, wherein said voltage source is equipped for providing a continuously varying voltage with a frequency, f, so that $f \times LT \geq 2.00$.

19. A method according to any of claims 15 to 18, wherein, before sending a print signal, for each line to be printed a printing element necessitating a shortest write time, WRT_{short}, of all printing elements in that line is determined and said frequency, f, is chosen so has to have $1.00/WRT_{short} \leq f \leq 4000$ Hz .

20. A method according to any of claims 15 to 19, wherein the step of sending a print signal for image-wise applying electric potentials to said printing elements is performed by sending a print signal, to said printing elements, within a line time, said print signal comprising pixel dots necessitating a write time shorter than said line time, and by positioning said write time, shorter than said line time, randomly over said line time.

21. A method according to claim 20, wherein, before sending said print signal, said write time, shorter than said line time is divided in portions and said print signal is adapted to send said portion in a random way during said line time.

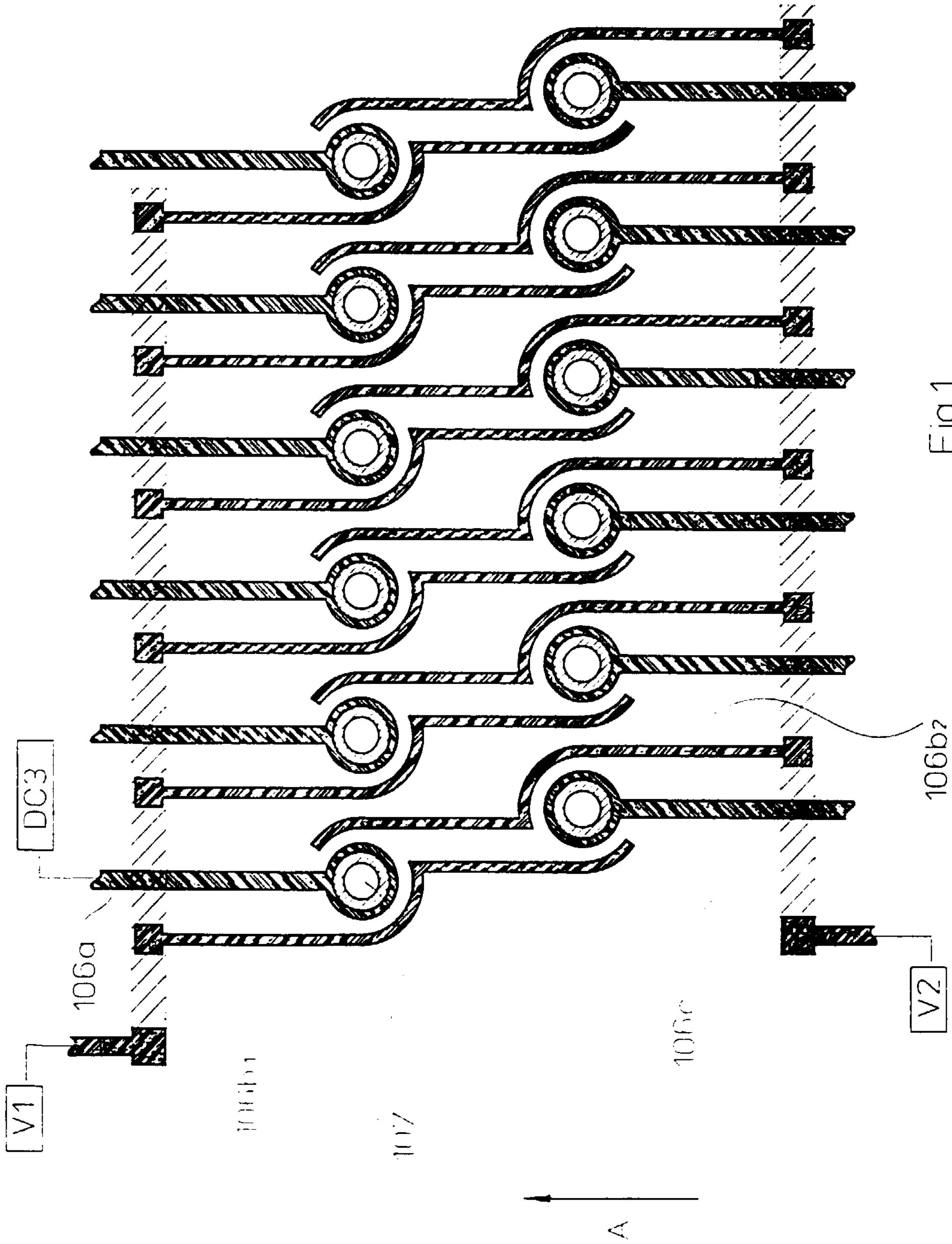


Fig.1
PRIOR ART

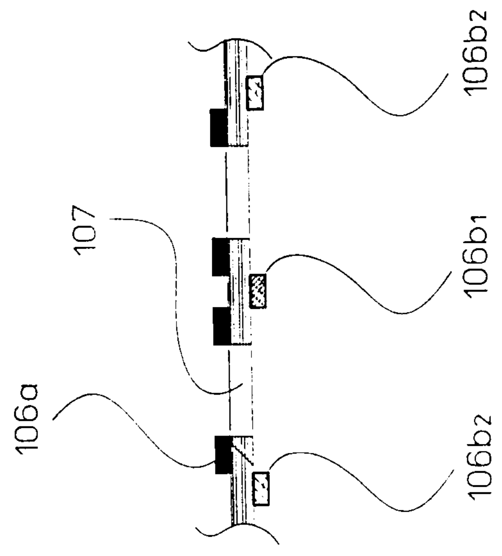


Fig.2c

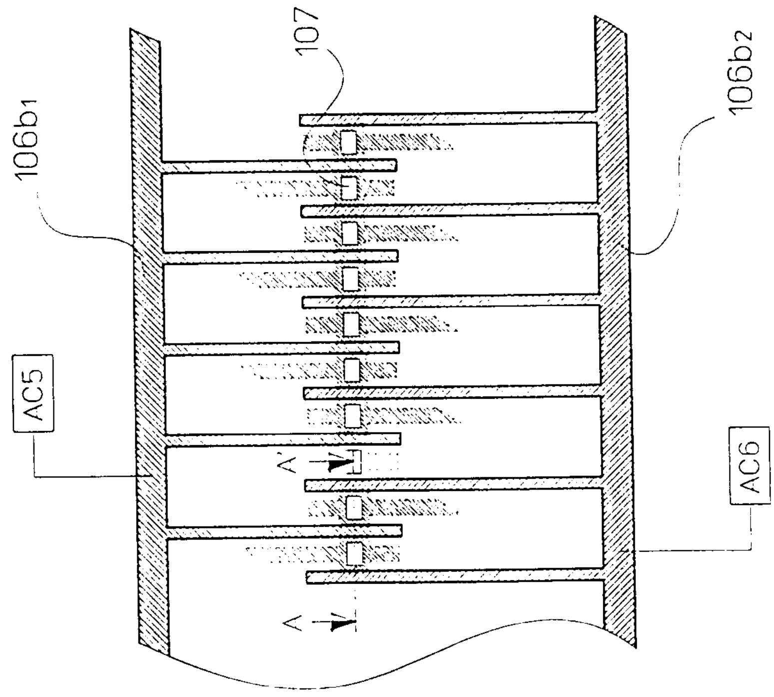


Fig.2b

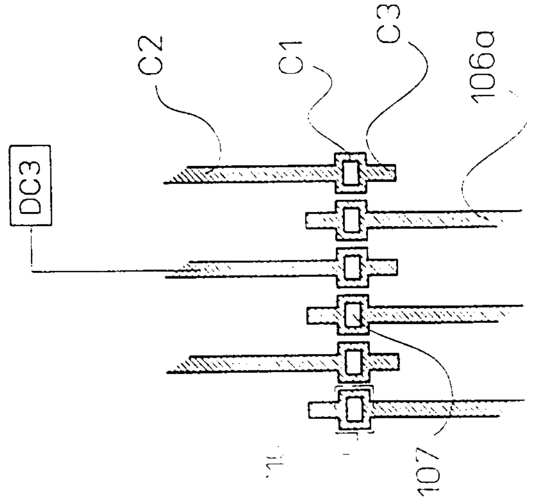


Fig.2a

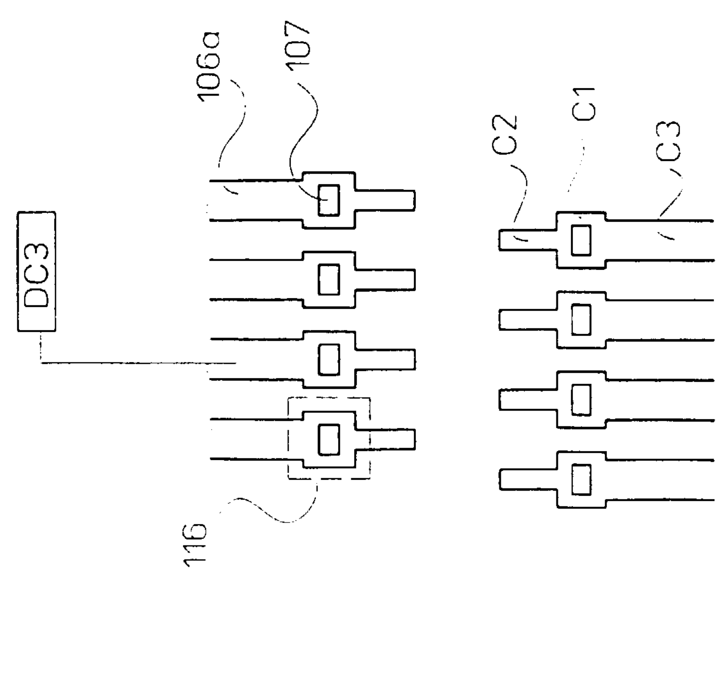


Fig.3a

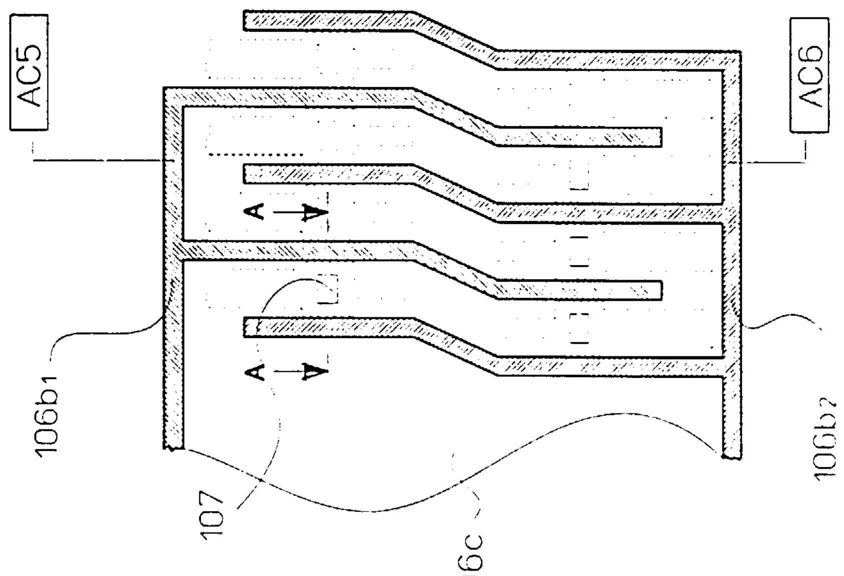


Fig.3b

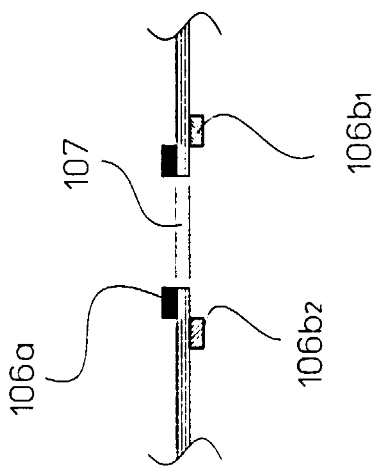


Fig.3c

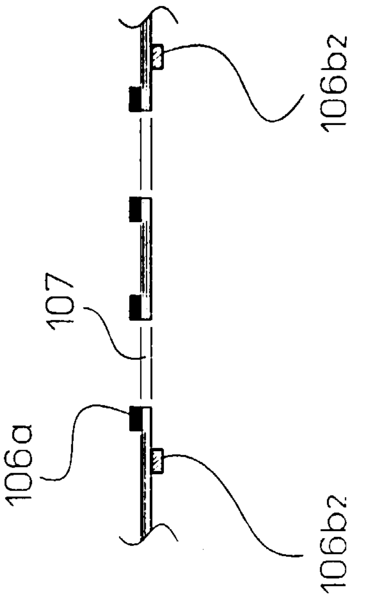


Fig.4c

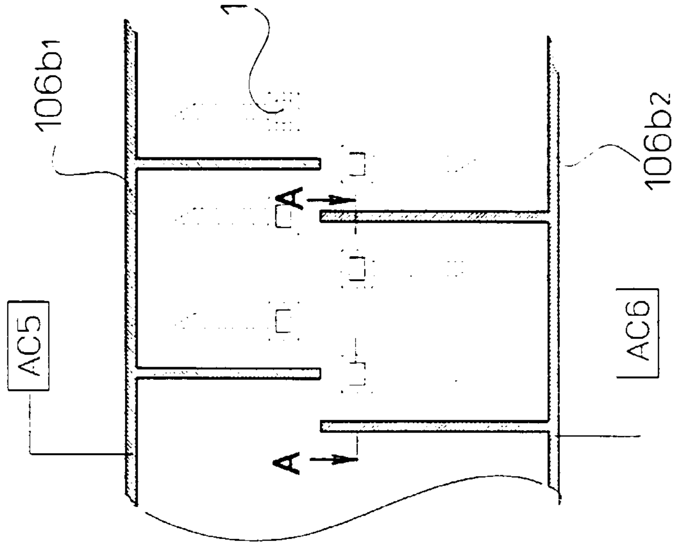


Fig.4b

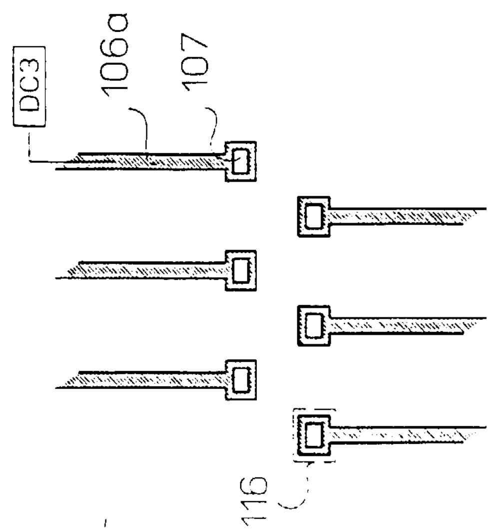


Fig.4a

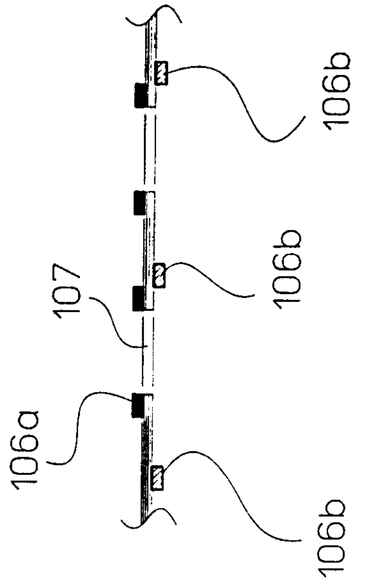


Fig 5c

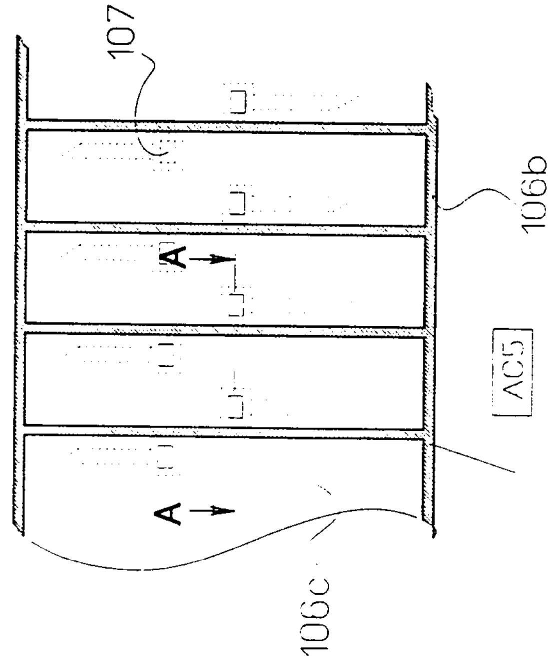


Fig 5b

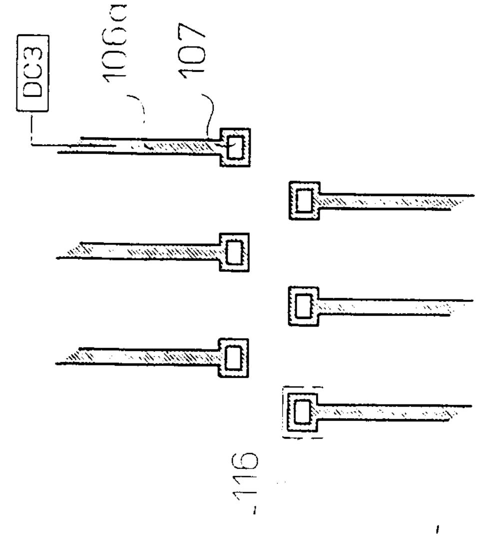


Fig 5a

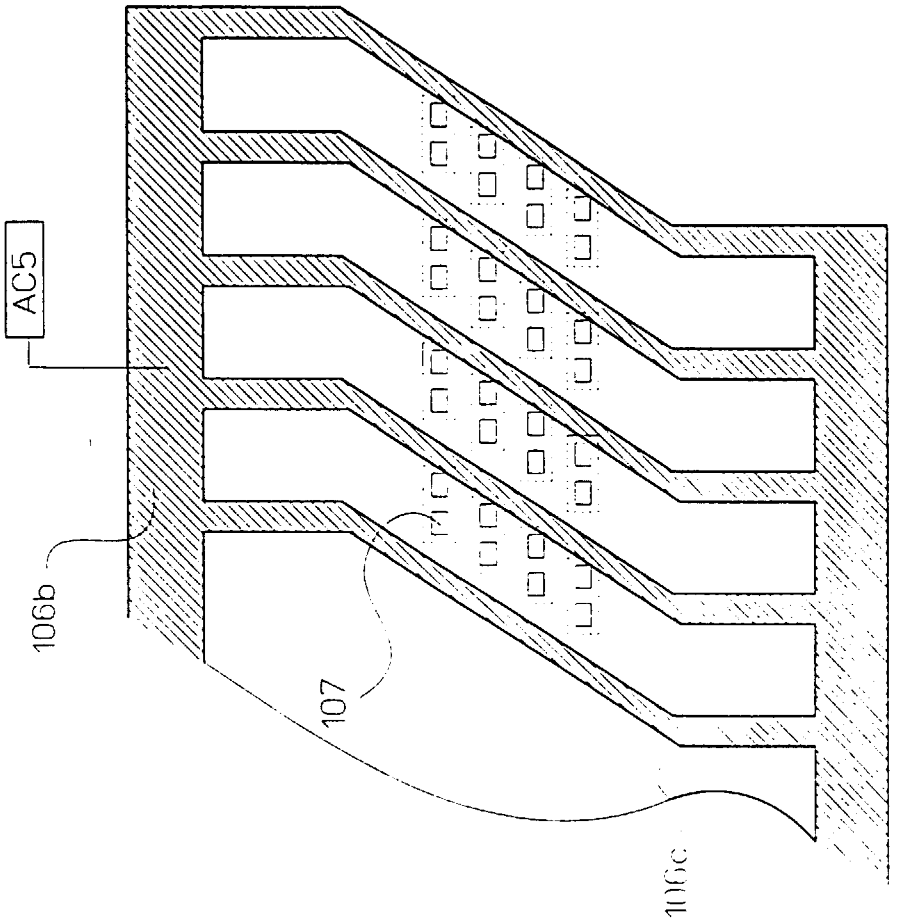


Fig.6b

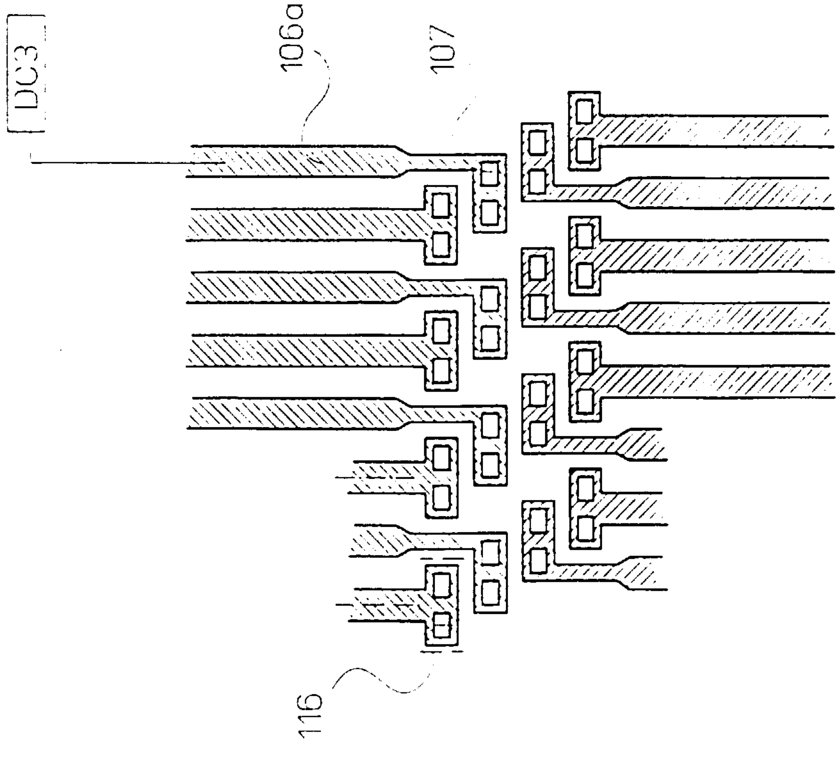
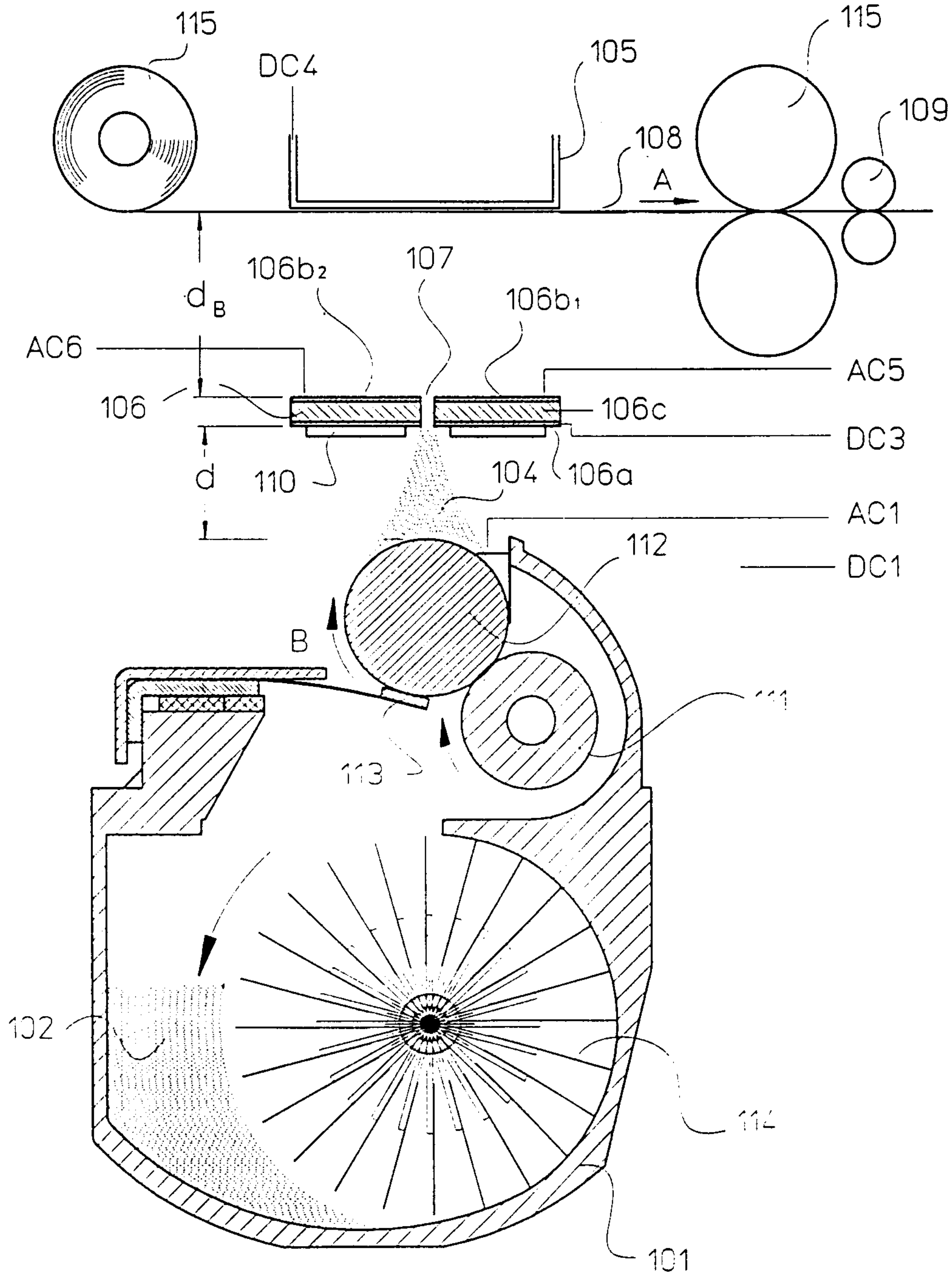


Fig.6a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DC4
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115
109
108
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106b1
AC6
AC5
106
106c
DC3
d
110
104
106a
AC1
112
DC1
B
111
113
102
114
101

Fig 7

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 20 0478

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION
D,A	DE 197 39 988 A (ARRAY PRINTERS AB) 19 March 1998 (1998-03-19) * the whole document * ---	1	B41J2/415
D,A	WO 97 35725 A (ARRAY PRINTERS AB) 2 October 1997 (1997-10-02) * the whole document * -----	1	

TECHNICAL FIELDS SEARCHED

B41J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	23 July 1999	De Groot, R

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 99 20 0478

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The members are as contained in the European Patent Office EDP file on
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23-07-1999

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82