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(71) Applicant: **EASTMAN KODAK COMPANY**
Rochester, New York 14650 (US)

(72) Inventor:
Wen, Yin,
c/o Eastman Kodak Company
Rochester, New York 14650-2201 (US)

(74) Representative:
Lewandowsky, Klaus, Dipl.-Ing. et al
Kodak Aktiengesellschaft,
Patentabteilung
70323 Stuttgart (DE)

(54) **Imaging apparatus and method adapted to control ink droplet volume and void formation**

(57) Imaging apparatus and method adapted to control ink droplet volume and void formation. The apparatus (10) includes an ink jet print head (45) having a nozzle (110) for ejecting an ink droplet (150) therefrom. A heater element (130) is in heat transfer communication with the ink droplet for variably supplying heat energy to the ink droplet, so that the volume of the ink droplet is controlled as the heat energy is variably supplied to the ink droplet. A controller (40) is connected to the heater element for variably controlling the heat energy supplied to the ink droplet. The controller varia-

bly controls the heat energy by variably controlling a plurality of voltage pulses sequentially supplied to the heater element. Moreover, in order to reduce the potential for void formation in the ink droplet, the pulses are spaced-apart by a predetermined delay interval. Suitable control of ink droplet volume and delay interval between pulses results in uniform print density and "gray-scaling" of each dot or pixel in the output image and also precludes void formation.

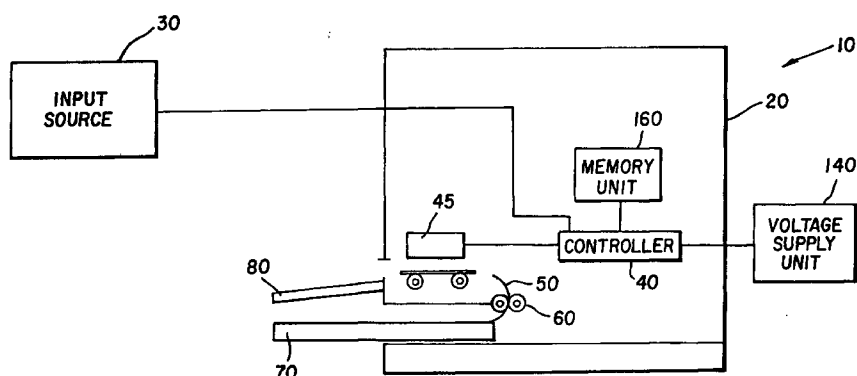


FIG. 1

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Description

FIELD OF THE INVENTION

The present invention relates generally to imaging apparatus and methods and, more particularly, to an imaging apparatus and method adapted to control ink droplet volume, so that printing non-uniformities, such as "banding", are avoided and so that print density can be controllably varied to provide gray-scaling at each dot or pixel of an output image, the imaging apparatus and method being also adapted to inhibit the potential for void formation in the ink.

BACKGROUND OF THE INVENTION

In a typical ink jet printer using a multi-nozzle head, data as to each of four colors (i.e., red, green, blue and black) regarding an input image are processed in a manner so that the multi-nozzle head forms a printed color output image on a recorder medium, which may be a suitable paper or transparency.

However, ink jet printers may produce non-uniform print density with respect to the image formed on the recorder medium. Such non-uniform print density may be visible as so-called "banding". Banding is evinced, for example, by repeated variations in the print density caused by delineations in individual dot rows comprising the output image. Thus, banding can appear as light or dark streaks or lines within a printed area. One factor causing banding is unintended variation in ink droplet volume. Unintended variation in ink droplet volume in turn may be caused by electrical resistance variation of a plurality of heaters in communication with the ink droplet, nozzle diameter variation, and/or the presence of damaged nozzles. Therefore, a problem in the art is non-uniform print density due to variation in nozzle physical attributes which in turn leads to variation in ink droplet volume.

Moreover, the ability of some prior art ink jet printers to produce halftone images has been limited because the ink jet print heads belonging to such printers produce ink droplets having a fixed volume. Marks produced by such droplets are of a fixed size and the same intensity. Consequently, these ink jet print heads utilize spot density, rather than spot size, to produce a gray-scale image. That is, these ink jet print heads produce various shades of gray by varying the density of the fixed size ink marks such that darker shades are produced by increasing spot density and lighter shades are produced by reducing spot density. However, such printers have reduced spatial resolution, thereby limiting the ability of the ink jet printer to produce finely detailed images. Spatial resolution is reduced because varying frequency of the constant spot size in a printed area obtains lower resolution when compared to keeping a constant frequency but varying the spot size. Moreover, directing multiple droplets at a single location of the

recorder medium to increase spot size tends to reduce the operating speed of the printer to an unacceptably low level and may even produce elongated or elliptical dot patterns. Therefore, another problem in the art is difficulty producing ink droplets that vary in size.

An ink jet printer device directed to controlling ink droplet volume and gray-scaling is disclosed in U.S. Patent No. 4,563,689 titled "Method For Ink-Jet Recording And Apparatus Therefor". This patent discloses an ink jet recording apparatus and process in which the droplet size is controlled to obtain halftone-graduation recording. According to this patent, a preceding pulse is applied to an electromechanical transducer prior to applying a main pulse so as to control the position of the ink meniscus in the nozzle and thereby control droplet size. However, this patent requires use of an electromechanical transducer to control ink droplet size. Use of an electromechanical transducer is not preferred because electromechanical transducers are difficult and costly to fabricate due to their structural complexity.

Another type of ink jet printer uses a resistance heater to reduce surface tension of the ink droplet in the nozzle orifice. Static back-pressure acting on the ink droplet coacts with the simultaneous decrease in surface tension to eject the ink droplet from the orifice and propel it toward the recorder medium. Means are provided to obtain uniform print density by controlling the heat energy supplied to the ink droplet. However, potential for heating of the ink in this type of ink jet printer can, at least theoretically, lead to boiling and void formation in the ink. Void formation is the formation of bubbles (i.e., voids) in the ink. Void formation is undesirable because the bubbles resulting from void formation could coalesce and block the nozzle orifice. Blocking the nozzle orifice interferes with proper ejection of the ink from the nozzle, thus leading to undesirable printing defects in the output image. Although this printer addresses the problem of banding, it does not expressly address the potential for void formation. Therefore, yet another problem in the art is the potential for void formation caused by excessive heating of the ink.

Therefore, an object of the present invention is to provide an imaging apparatus and method adapted to control ink droplet volume, so that printing of anomalous non-uniformities, such as "banding", are avoided and so that print density can be controllably varied to provide gray-scaling at each dot or pixel and so that the potential for void formation in the ink is reduced.

SUMMARY OF THE INVENTION

The invention in its broad form resides in an imaging apparatus, comprising a nozzle for ejecting print fluid therefrom, the print fluid having a volume defined by heat energy supplied to the print fluid and having a potential for void formation; a heater adapted to be in heat transfer communication with the print fluid for supplying the heat energy to the print fluid; and a controller

connected to the heater for variably controlling a plurality of voltage pulses supplied to the heater in order to variably control the heat energy supplied by the heater, whereby the volume of the print fluid ejected from the nozzle is variably controlled as the controller variably controls the heat energy and whereby the potential for void formation in the print fluid is reduced as the controller variably controls the heat energy.

A feature of the present invention is the provision of a plurality of heater elements associated with respective ones of a plurality of nozzles, each heater element being in heat transfer communication with print fluid in the nozzle for heating the print fluid.

Another feature of the present invention is the provision of a controller connected to the heater elements for supplying a plurality of voltage pulses to each of the heater elements, the pulses having a predetermined pulse amplitude and a predetermined pulse width to control the volume of print fluid released from the nozzle, the pulses being separated by a predetermined delay interval in order to reduce the potential for void formation in the print fluid.

Still another feature of the present invention is the provision of a memory unit connected to the controller for storing values of print density as a function of ink droplet volume for each nozzle, the memory unit capable of informing the controller of the correct ink droplet volume required from each nozzle in order to obtain a uniform print density for the output image and to obtain a desired gray-scale level at each dot or pixel.

Yet another feature of the present invention is the provision of a memory unit connected to the controller for storing values of ink droplet volume as a function of voltage pulse amplitude and voltage pulse width supplied to each nozzle, the memory unit capable of informing the controller of the pulse amplitude and pulse width to be supplied to each nozzle in order to obtain a desired ink droplet volume from each nozzle.

An advantage of the present invention is that use thereof eliminates visual printing defects, such as "banding", even in the presence of variations in such physical attributes as electrical resistance of the heater, variation in the diameter of the nozzle orifice, and/or the presence of damaged nozzles.

Another advantage of the present invention is that use thereof provides for multi-density scales (i.e., gray-scaling) at each dot or pixel location without use of an electromechanical transducer.

A further advantage of the present invention is that use thereof reduces the potential for void formation in the ink to be ejected from the nozzle.

These and other objects, features and advantages of the present invention will become apparent to those skilled in the art upon a reading of the following detailed description when taken in conjunction with the drawings wherein there is shown and described illustrative embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In the detailed description of the preferred embodiments of the invention presented hereinbelow, reference is made to the accompanying drawings, in which:

FIG. 1 is a view in partial vertical section, with parts removed for clarity, of an imaging apparatus, this view showing an ink-jet print head for printing an image onto a recorder medium, this view also showing a controller connected to the print head for controlling volume of ink droplets ejected from the print head and for controlling delay interval between a plurality of voltage pulses supplied to the print head;

FIG. 2 is a view in horizontal section of a portion of the print head, this view also showing a plurality of nozzles and associated cavities filled with ink, each of the nozzles having an electric resistance heater in heat transfer communication with the ink therein; FIG. 3 is a detail view in horizontal section of one of the nozzles;

FIG. 4 is a view in vertical section of the nozzle showing the ink being restrained by surface tension from emerging from the nozzle;

FIG. 5 is a view in vertical section of the nozzle showing an ink droplet emerging from the nozzle as the surface tension begins to relax;

FIG. 6 is a view in vertical section of the nozzle showing the ink droplet emerging further from the nozzle as the surface tension further relaxes;

FIG. 7 is a view in vertical section of the nozzle showing the ink droplet having emerged from the nozzle and propelled toward the recorder medium by back-pressure;

FIG. 8 is a graph illustrating voltage amplitude as a function of time, this graph also showing a plurality of voltage pulses having an identical pulse amplitude V_p and an identical pulse width T , the voltage pulses being spaced-apart by a predetermined delay interval τ ;

FIG. 9 is a graph illustrating voltage amplitude as a function of time, this graph also showing a plurality of voltage pulses having an identical pulse amplitude V_p combined with pulse widths T decreasing with respect to time, the voltage pulses being spaced-apart by a predetermined delay interval τ ; and

FIG. 10 is a graph illustrating voltage amplitude as a function of time, this graph also showing a plurality of voltage pulses having decreasing pulse amplitudes V_p combined with an identical pulse width T , the voltage pulses being spaced-apart by a predetermined delay interval τ .

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1, there is shown an imaging appa-

ratus, generally referred to as 10, capable of varying ink droplet volume at each pixel of an output image, capable of producing the output image so that the output image lacks printing defects such as "banding", and capable of reducing the potential for void formation in the ink droplet. Imaging apparatus 10 comprises a printer, generally referred to as 20, electrically connected to an input source 30 for reasons disclosed hereinbelow. Input source 30 may provide raster image data from a scanner or computer, outline image data in the form of a page description language, or other form of digital image data. The output signal generated by input source 30 is received by a controller 40, for reasons disclosed in detail hereinbelow.

Referring to Figs. 1 and 2, controller 40 processes the output signal generated by input source 30 and generates a controller output signal that is received by a print head 45 which is capable of printing on a recorder medium 50. Recorder medium 50 is reciprocatingly fed past print head 45 at a predetermined feed rate by a plurality of rollers 60 (only some of which are shown). More specifically, recorder medium 50 is reciprocatingly moved adjacent print head 45 in order to sequentially apply four colors (i.e., red, green, blue and black) of an input image file onto recorder medium 50. Recorder medium 50 is fed, by rollers 60, from an input supply tray 70 containing a supply of recorder medium 50. Each line of image information from input source 30 is printed on recorder medium 50 as that line of image information is communicated from input source 30 to controller 40. Controller 40 in turn communicates that line of image information to print head 45 as recorder medium 50 moves relative to print head 45. When a completely printed image is formed on recorder medium 50, recorder medium 50 exits the interior of printer 20 to be deposited in an output tray 80 for retrieval by an operator of imaging apparatus 10. Although the terminology referring to "print head 45" is used in the singular, it is appreciated by a person of ordinary skill in the art that the terminology "print head 45" is intended also to include its plural form because there may be, for example, four print heads 45, each of the print heads 45 being respectively dedicated to printing one of the previously mentioned four colors (i.e., red, green, blue and black).

Turning now to Figs. 1, 2, 3, and 4, print head 45, which belongs to printer 20, is there shown in operative condition for printing an image on recorder medium 50. Print head 45 comprises a plurality of ink fluid cavities 90 for holding print fluid, such as a body of ink 100. Moreover, associated with each cavity 90 is a nozzle 110 for allowing ink 100 to exit cavity 90 under a suitable back pressure (e.g., 15 psi). In this regard, each nozzle 110 includes a generally circular orifice 120 in fluid communication with ink 100. Orifice 120, which is disposed proximate recorder medium 50, opens toward recorder medium 50 for depositing ink 100 onto recorder medium 50. Moreover, surrounding orifice 120 is a generally

annular electrothermal actuator (i.e., an electrical resistance heater element) 130 for heating ink 100. Thus, each heater 130 is in heat transfer communication with ink 100. A voltage supply unit 140 is electrically connected to print head 45 (via controller 40) for supplying a plurality of controlled voltage pulses to each heater 130, for reasons disclosed in detail hereinbelow. Controller 40 controls the pulse amplitude, pulse width and delay interval between voltage pulses so that ink droplet volume at each nozzle 110 is controlled in order to control print density produced by each nozzle 110 and so that the potential for void formation in ink body 100 is reduced as ink body 100 is heated. Controlling print density at each nozzle 110 allows "gray scale" printing at each nozzle 110 and eliminates undesirable "banding", as described more fully hereinbelow. Moreover, controlling the potential for void formation in ink body 100 reduces risk of blocking orifice 120 by coalescence of bubbles thereat.

As best seen in Figs. 5 and 6, an ink bulge, meniscus or droplet 150 outwardly emerges from orifice 120 as resistance heater 130 increases temperature in order to heat droplet 150. This heating of droplet 150 results in a localized decrease in surface tension of droplet 150, so that droplet 150 is eventually released from orifice 120 when the surface tension becomes insufficient to overcome the back-pressure acting on droplet 150.

Fig. 7 shows droplet 150 separated from ink body 100 and ejected from orifice 120 as it is propelled outwardly toward recorder medium 50 to establish an ink mark upon recorder medium 50. Droplet 150 eventually will be intercepted by recorder medium 50 to "soak into" and be absorbed by recorder medium 50. Of course, the image printed onto recorder medium 50 should possess a uniform print density to avoid banding and should produce an appropriate gray-scale at each dot or pixel of the image. In addition, the amount of heat energy supplied to ink body 100 by heater 130 should not be in an amount to cause void formation in ink body 100.

However, it is known that "banding" (i.e., print density non-uniformity) is a recurring problem in the printing arts. Banding is usually caused by variability in the diameter of orifice 120 or by variability in electrical resistance among resistance heaters 130. Even small variations in diameter and electrical resistance can lead to visible "banding".

Moreover, it is known that some prior art ink jet printers have difficulty producing gray-scale images because the prior art ink jet print heads belonging to such printers produce ink droplets having a fixed volume. Consequently, such printers produce shades of gray by varying the density of the fixed size of the ink droplet. However, images provided by this method lack fine detail due to reduced spatial resolution.

In addition, it is known that excessive heating of ink body 100 or excessive heat energy input to ink body 100 raises at least the potential for boiling or void formation

in ink body 100. Void formation in ink body 100 is undesirable because the bubbles resulting from void formation may coalesce and block orifice 120, thereby interfering with proper ejection of ink from orifice 120. Interference with ejection of ink from orifice 120 produces defects in the output image printed on recorder medium 50.

To solve the problems recited hereinabove, the present invention supplies a plurality or series of voltage pulses to each heater 130 and controls the pulse amplitude, pulse width and delay interval between pulses. Controlling these control parameters compensate for physical anomalies (e.g., variations in the diameter of orifice 120, and/or variations in electrical resistance of heaters 130) associated with individual nozzles 110 to obtain uniform print density on recorder medium 50 and "gray-scaling" at each dot or pixel and also reduces the potential for void formation in ink body 100. This result is attainable because controlling the voltage pulse amplitude and/or voltage pulse width controls the surface tension of ink droplet 150, which in turn controls the volume of ink released from each nozzle 110. Of course, controlling the volume of ink released from each nozzle 110 controls the print density and the amount of gray-scaling provided by each nozzle 110. In addition, controlling the delay interval between pulses controls the rate at which heat energy is supplied to ink body 100, so as to reduce the potential for void formation in ink body 100.

To ensure uniform print density, each nozzle 110 of a selected print head 45 is calibrated. In this regard, a plurality of test images are produced with print head 45 to determine the print density (i.e., droplet volume) produced by each nozzle 110 given a predetermined voltage pulse amplitude and pulse width supplied to each of the heaters 130 associated with respective ones of the nozzles 110. This data is then stored in a memory unit or semiconductor chip 160, which is connected to controller 40 (see Fig. 1). Chip 160 may, for example, be a Read-Only-Memory (ROM) semiconductor computer chip. Controller 40 is informed by the values of pulse amplitude and pulse width stored in chip 160 as to the correct pulse amplitude and pulse width to apply to each nozzle 110 in order to obtain uniform print density among nozzles 110 and in order to obtain the desired gray-scale level at each dot or pixel of the output image.

By way of example only and not by way of limitation, representative embodiments of the multi-pulse inventive concept taught herein is provided hereinbelow.

Fig. 8 shows a plurality of voltage pulses supplied to a selected heater 130 for controlling droplet volume released from nozzle 110 associated with heater 130. Each of the pulses has an identical pulse amplitude V_p and an identical pulse width T , the voltage pulses being spaced-apart by a predetermined delay interval τ . Each pulse belonging to these intermittent voltage pulses allows the heated ink droplet 150 to move out of the vicinity of heater 130 before the next pulse is supplied. This technique extends heating time and increases the

volume of ink droplet 150. Moreover, this string of pulses also effectively merge any separate droplets into one droplet to increase the density scale (i.e., gray-scale) at each dot or pixel of the output image. In addition, pulse amplitude V_p , pulse width T and delay interval τ are chosen so that the amount of heat energy supplied to ink 100 is never sufficient to induce bubbles or void formation in ink 100. In this regard, it is appreciated that it takes more time to supply a given amount of heat energy to ink 100 using the plurality of pulses shown in Fig. 8 than it takes to supply the same amount of heat energy to ink 100 using a single pulse. This is primarily due to the presence of delay interval τ and an otherwise reduced value of pulse amplitude V_p . Hence, boiling in ink 100 is precluded by use of the invention because heat energy supplied to ink 100 to sufficiently reduce the surface tension of droplet 150 occurs over a longer time than in the case of a single pulse. In other words, the rate of heat energy supplied to ink 100 is less using the plurality of pulses of Fig. 8 than with a single pulse. In addition, it should be understood from the teachings herein that delay interval τ need not be a constant value and, thus, may vary among the pulses.

Fig. 9 shows a plurality of voltage pulses supplied to a selected heater 130 for controlling droplet volume released from nozzle 110 associated with heater 130. Each of the pulses has an identical pulse amplitude V_p and pulse widths T decreasing with respect to time, the voltage pulses being spaced-apart by a predetermined delay interval τ . Again, pulse amplitude V_p , pulse width T and delay interval τ are chosen so that the amount of heat energy supplied to ink 100 is never sufficient to induce bubbles or void formation in ink 100. In addition, the pulse widths T shown in Fig. 9 are greater earlier during heat energy input to ink 100 in order to supply the maximum amount of heat energy subject to a constraint that boiling not be induced in ink 100. Moreover, the pulses are spaced-apart by delay interval τ to reduce the potential for boiling.

Fig. 10 shows a plurality of voltage pulses supplied to a selected heater 130 for controlling droplet volume released from nozzle 110 associated with heater 130. The pulses have pulse amplitudes V_p decreasing with respect to time and identical pulse widths T , the voltage pulses being spaced-apart by a predetermined delay interval τ . The pulse amplitudes V_p shown in Fig. 10 are greater earlier during heat energy input to ink 100 in order to supply the maximum amount of heat energy subject to the constraint that boiling not be induced in ink 100. Moreover, the pulses are spaced-apart by delay interval τ to reduce the potential for boiling.

It is appreciated from the teachings herein, that an advantage of the present invention is that images of uniform print density are provided even in the presence of variations in physical attributes such as electrical resistance of the heaters 130 and/or diameter of the nozzle orifices 120. This is so because each nozzle 110 is calibrated to compensate for such variability among noz-

zles 110. This eliminates visual printing defects, such as "banding".

A further advantage of the present invention is that each nozzle 110 is capable of obtaining gray-scale printing simultaneously with obtaining uniform print density because the volume of ink released by each nozzle 110 is controlled.

Yet another advantage of the present invention is that the potential for void formation in the ink is reduced. This is so because an otherwise single voltage pulse is partitioned into a plurality of spaced-apart pulses in order to avoid excessive heating of the ink.

While the invention has been described with particular reference to a several preferred embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements of the preferred embodiment without departing from the spirit and scope of the invention. In addition, many modifications may be made to adapt a particular situation and material to a teaching of the present invention without departing from the essential teachings of the invention. For example, the invention is described as supplying any one of the wave forms illustrated in Figs. 8 through 10. However, the wave forms illustrated in each of the Figs. 8 through 10 are representative only. That is, any combination of voltage amplitude V_p , pulse width T and delay interval τ may be chosen such that the rate of heat energy input to ink 100 is maximized subject to the constraint that boiling not be induced in ink 100.

Therefore, what is provided is an imaging apparatus and method for providing images of uniform print density, so that printing non-uniformities, such as banding, are avoided, so that gray-scaling can be achieved at each dot or pixel of the output image, and so that the potential for void formation is reduced.

PARTS LIST

10	imaging apparatus	
20	printer	
30	input source	
40	controller	
45	printhead	
50	recorder medium	
60	rollers	
70	supply tray	
80	output tray	
90	ink fluid cavities	
100	body of ink	
110	nozzle	
120	orifice	
130	heater	
140	voltage supply unit	
150	ink droplet	
160	memory unit/computer chip	

Claims

1. An imaging apparatus (10) adapted to control ink droplet volume and void formation, characterized by:
 - (a) a nozzle (110) for ejecting an ink droplet (150) therefrom, the ink droplet having a volume defined by heat energy supplied to the ink droplet and having a potential for void formation;
 - (b) a heater element (130) adapted to be in heat transfer communication with the ink droplet for supplying the heat energy to the ink droplet; and
 - (c) a controller (40) connected to said heater element for variably controlling the heat energy supplied by said heater element, said controller variably controlling the heat energy by variably controlling a plurality of voltage pulses sequentially supplied to said heater element, each of the voltage pulses having a predetermined pulse amplitude and a predetermined pulse width variably controlled by said controller, whereby the volume of the ink droplet ejected from said nozzle is variably controlled as said controller variably controls the pulse amplitude and the pulse width and whereby potential for void formation in the ink droplet is reduced as said controller variably controls the pulse amplitude and the pulse width.
2. The imaging apparatus of claim 1, wherein said controller variably controls each voltage pulse so that the pulses are spaced-apart in time by a predetermined delay interval.
3. The imaging apparatus of claim 1, wherein said controller variably controls the pulse amplitude and the pulse width of each pulse so that the pulses have an identical pulse amplitude and an identical pulse width.
4. The imaging apparatus of claim 1, wherein said controller variably controls the pulse amplitude and the pulse width of each pulse so as to define a first pulse followed in time by a second pulse having an identical pulse amplitude as the pulse amplitude of the first pulse and a pulse width less than the pulse width of the first pulse, the first pulse and the second pulse being spaced-apart in time by a predetermined delay interval.
5. The imaging apparatus of claim 1, wherein said controller variably controls the pulse amplitude and the pulse width of each pulse so as to define a first pulse followed in time by a second pulse having an identical pulse width as the pulse width of the first

pulse and a pulse amplitude less than the pulse amplitude of the first pulse, the first pulse and the second pulse being spaced-apart in time by a predetermined delay interval.

6. The imaging apparatus of claim 1, further characterized by a memory unit (160) connected to said controller for storing data including fluid volume as a function of a predetermined control parameter.

7. The imaging apparatus of claim 1, further characterized by a memory unit connected to said controller for storing data including print density as a function of a predetermined control parameter.

8. The imaging apparatus of claim 7, wherein said memory unit is characterized by a read-only memory unit.

9. An imaging method of controlling ink droplet volume and void formation, characterized by the steps of:

(a) providing a nozzle (110) adapted to eject an ink droplet therefrom, the ink droplet having a volume defined by heat energy supplied to the ink droplet and having a potential for void formation;

(b) providing a heater element (130) adapted to be in heat transfer communication with the ink droplet for supplying the heat energy to the ink droplet;

(c) providing a controller (40) connected to the heater element for variably controlling a plurality of voltage pulses supplied to the heater in order to variably control the heat energy supplied by the heater element by variably controlling a plurality of voltage pulses sequentially supplied to the heater element, each of the voltage pulses having a predetermined pulse amplitude and a predetermined pulse width, so that the volume of the ink droplet ejected from the nozzle is variably controlled as the controller variably controls the heat energy and so that the potential for void formation in the ink droplet is reduced as the controller variably controls the heat energy.

10. The imaging method of claim 9, wherein said step of providing a controller is characterized by the step of providing a controller capable of variably controlling each voltage pulse so that adjacent ones of the pulses are spaced-apart in time by a predetermined delay interval.

11. The imaging method of claim 9, wherein said step of providing a controller is characterized by the step of providing a controller capable of variably control-

ling the pulse amplitude and the pulse width so that the pulses have an identical pulse amplitude and an identical pulse width, adjacent ones of the pulses being spaced-apart in time by a predetermined delay interval.

12. The imaging method of claim 9, wherein said step of providing a controller is characterized by the step of providing a controller capable of variably controlling the pulse amplitude and the pulse width so as to define a first pulse followed in time by a second pulse having an identical pulse amplitude as the pulse amplitude of the first pulse and a pulse width less than the pulse width of the first pulse, the first pulse and the second pulse being spaced-apart in time by a predetermined delay interval.

13. The imaging method of claim 9, wherein said step of providing a controller is characterized by the step of providing a controller capable of variably controlling the pulse amplitude and the pulse width so as to define a first pulse followed in time by a second pulse having an identical pulse width as the pulse width of the first pulse and a pulse amplitude less than the pulse amplitude of the first pulse, the first pulse and the second pulse being spaced-apart in time by a predetermined delay interval.

14. The imaging method of claim 9, wherein said step of providing a controller is characterized by the step of providing a memory unit (160) for storing data including fluid volume as a function of a predetermined control parameter.

15. The imaging method of claim 14, wherein said step of providing a memory unit is characterized by the step of providing a read-only memory unit (160).

16. The imaging method of claim 9, wherein said step of providing a controller is characterized by the step of providing a memory unit for storing data including print density as a function of a predetermined control parameter.

17. The imaging method of claim 16, wherein said step of providing a memory unit is characterized by the step of providing a read-only memory unit.

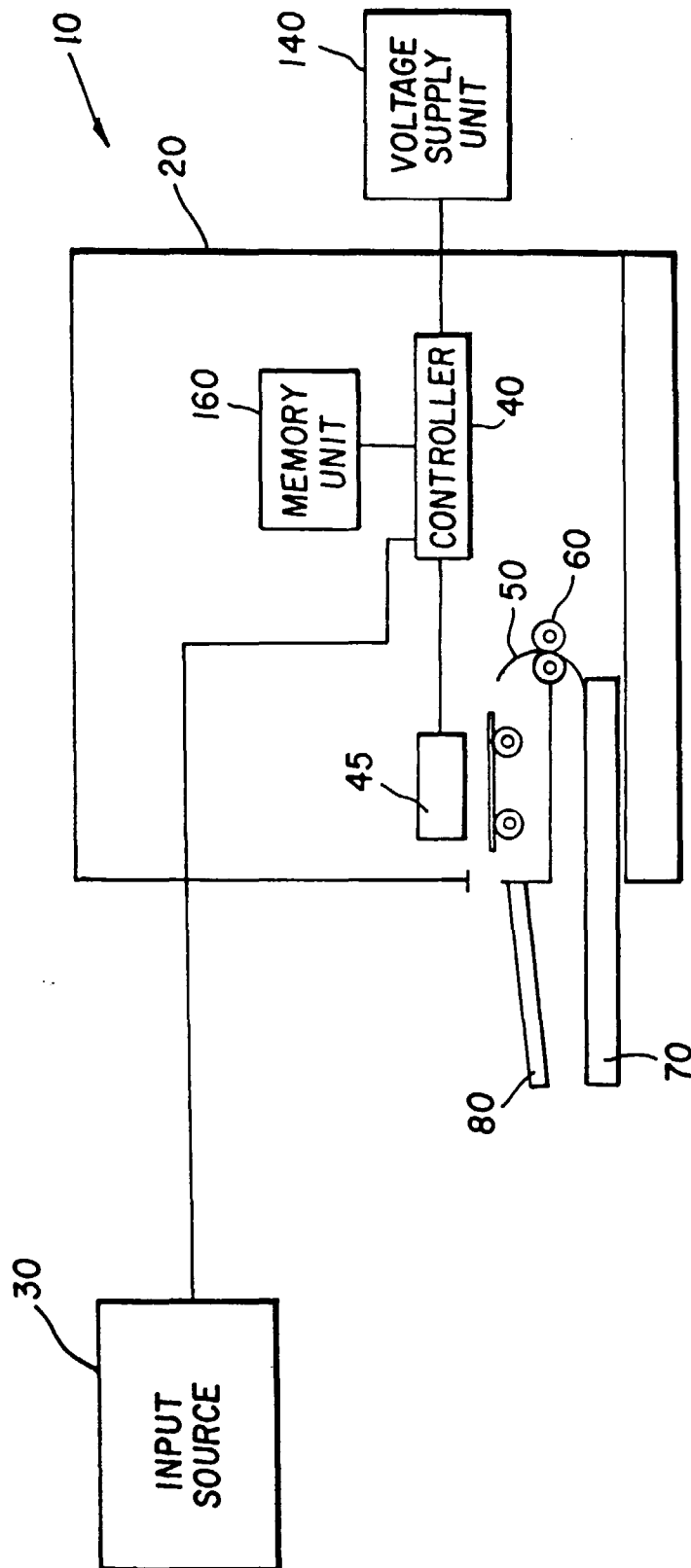


FIG. 1

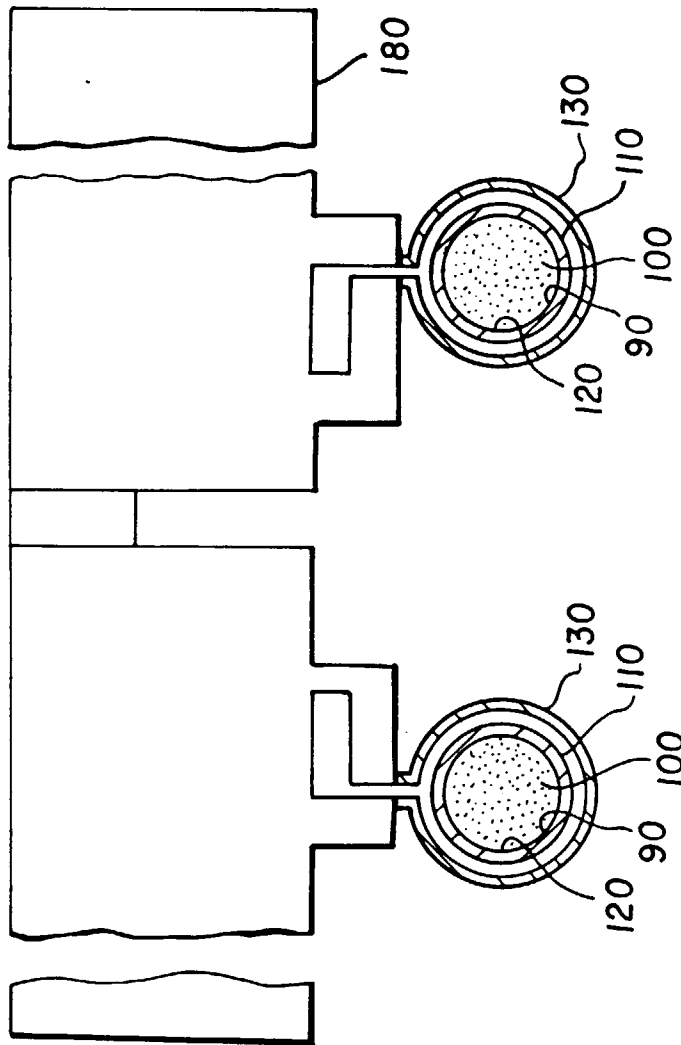


FIG. 2

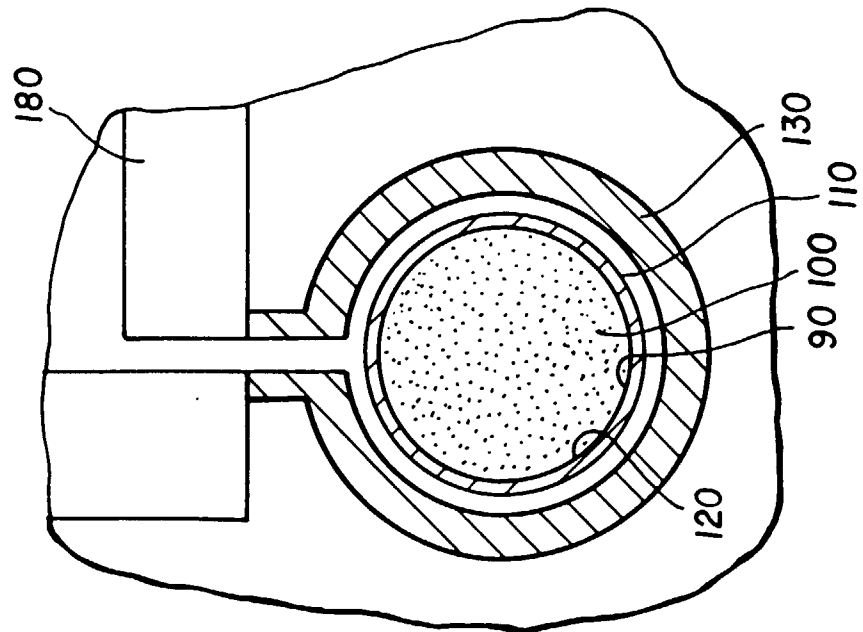


FIG. 3

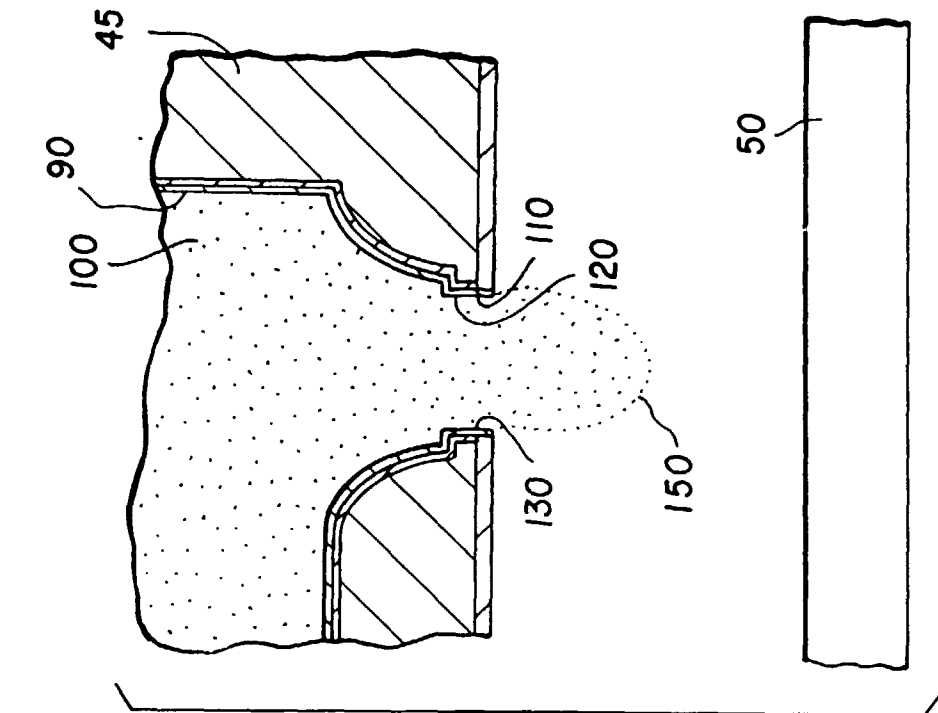


FIG. 4

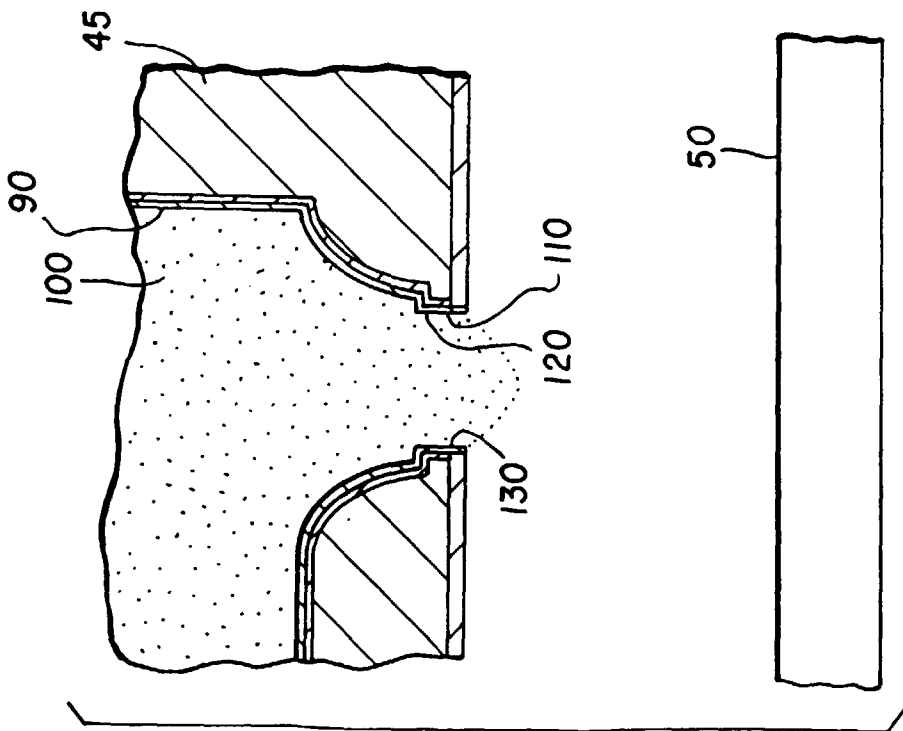


FIG. 5

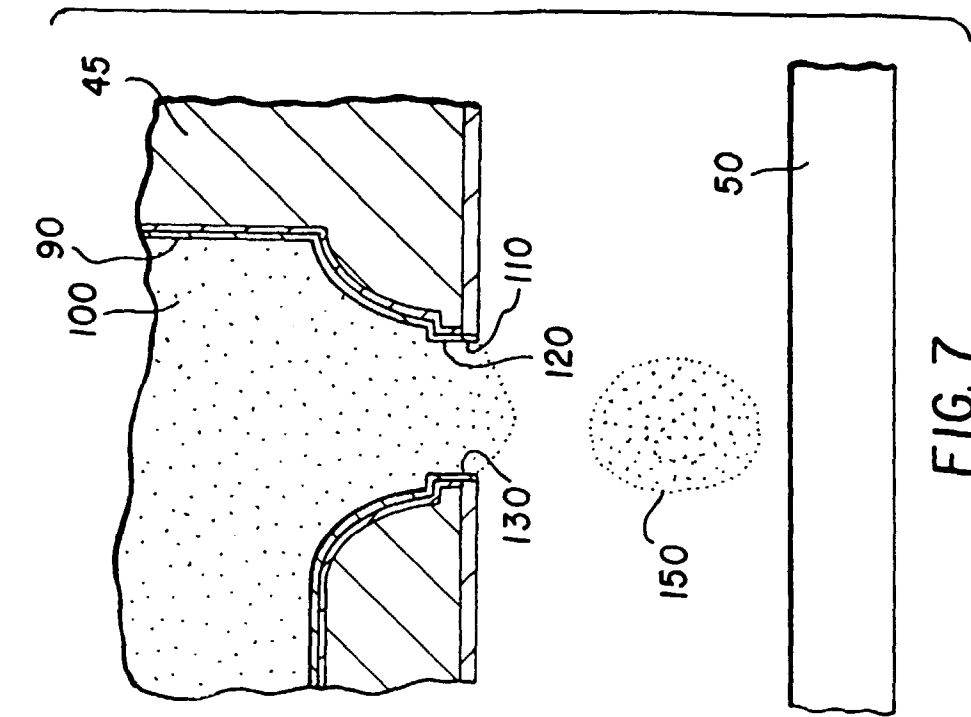


FIG. 6

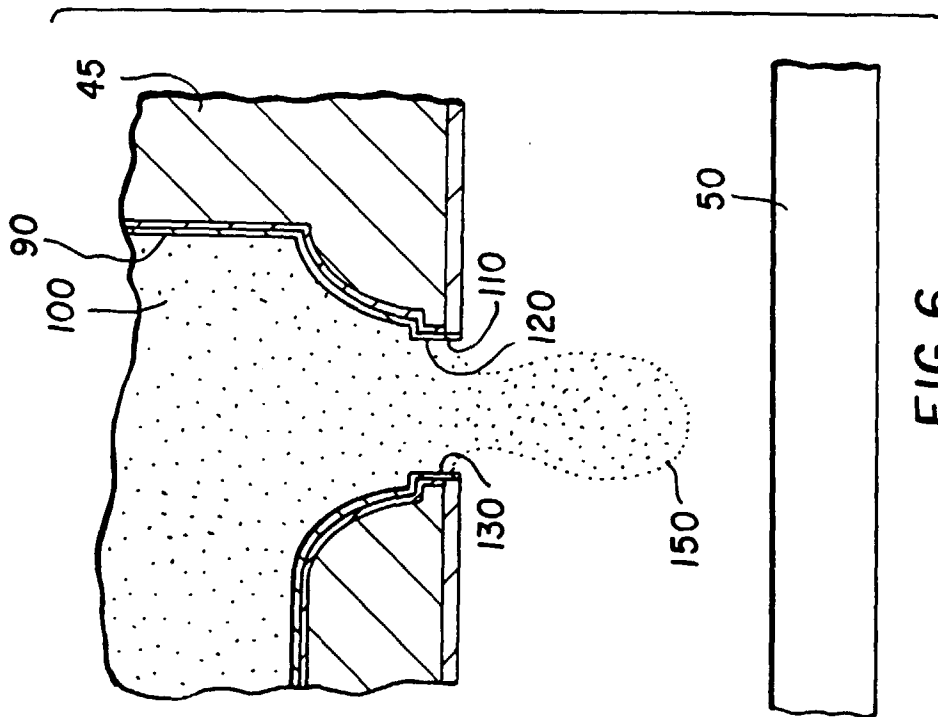


FIG. 7

