Method and apparatus for controlling inkjet nozzle loading

An inkjet nozzle (60,80) having a channel (14) and chamber (16), also includes a damping structure (62, 82) about the nozzle channel for actively restricting ink flow through the channel. According to alternative embodiments the damping structure is a capacitive structure (62) and/or an inductive structure (82). A capacitive structure sets up a voltage potential across the channel width (e.g., diameter). Charge centers in the ink respond to the field. When a nozzle is fired, the capacitive structure discharges to ground and ink flows through the channel under passive flow conditions. Thereafter, the capacitive structure is recharged slowing the ink flow. The field potential is set up causing ink flow to taper off as a desired volume approaches and restrict back-flow once the desired volume is achieved. The inductive structure operates similarly, but creates a magnetic field. Ferromagnetic ink responds to the field so as to slow ink flow and restrict back-flow. As a result, the conventional flow and ebb cycle during nozzle loading is shortened and steady state chamber conditions are reached in less time.
Description

BACKGROUND OF THE INVENTION

This invention relates generally to inkjet printhead nozzle structures and methods and apparatus for controlling ink flow within a nozzle. More particularly, this invention relates to active methods and corresponding apparatus for controlling inkjet nozzle loading.

An inkjet printhead includes multiple nozzles for ejecting ink onto a print media to form character, symbols and/or graphics. Typically, the ink is stored in a reservoir and passively loaded into nozzles via respective nozzle channels. For example, capillary action moves the ink from the reservoir through small nozzle channels into respective nozzle chambers. A firing resistor in a respective chamber then is activated and ejects the ink out of the nozzle. The geometry of a given channel defines how quickly a corresponding nozzle chamber is refilled after nozzle firing.

Typical passive loading of a nozzle chamber includes the rapid flow of ink into the chamber after the nozzle fires. The ink flow action is characterized as a repeating flow and ebb process in which ink flows into the chamber, then back-flows slightly. Channel geometry defines passive damping qualities which limit the inflow and determines a steady-state chamber height. The flow and ebb cycle is passively damped until a steady state chamber level is maintained. Thereafter, the nozzle is fired. The damping flow and ebb characteristic of passive nozzle loading occurs over a known period of time. Nozzle firing can occur any time after such period, and result in ejection of an ink drop with known repeatable volume and shape.

One goal of printing is to print at increasingly high printing speeds. As printing speed requirements increase, the nozzle firing frequency increases. The period betweenfirings, therefore decreases. As such firing period decreases to approach or become less than the passive flow and ebb loading period, the ability to form ink drops of uniform volume and shape decreases. Specifically, some nozzles may be fired during a flow phase and thereby generate larger ink drops than other nozzles which fire during a steady-state or an ebb phase. Accordingly, as printing speed requirements increase, the nozzle loading times need to decrease. As passive loading schemes are inherently limited to a given loading period, there is a need for a method and apparatus which actively damps the flow and ebb cycle of nozzle loading to decrease nozzle loading time.

Another goal of printing is to print at increasingly improved resolution. To achieve increased print resolution using inkjet technology, it is desirable to print with smaller ink drops. Smaller ink drops are created using smaller nozzle chambers. For smaller nozzle chambers, smaller channel geometries are needed to reliably move the ink via capillary action. As the nozzle dimensions decrease, however, it becomes more difficult for conventional fabrication processes to control channel dimensions. As the channel dimensions control the ink flow and ebb, it becomes more difficult to passively control damping for smaller ink drop sizes. Accordingly, there is a need for a method and apparatus which actively damps the flow and ebb cycle of nozzle loading.

SUMMARY OF THE INVENTION

According to the invention an ink loading control method and apparatus actively damps ink flow (including back-flow) in an inkjet nozzle. In particular ink flow into an inkjet nozzle channel is throttled at a nozzle channel to damp ink flow into the chamber, to reduce ink back-flow out of the chamber, and to achieve steady-state chamber conditions in a shorter time than under comparable passive ink loading schemes.

According to one aspect of the invention, a capacitive damping structure is implemented. The capacitive structure is defined at a nozzle channel to slow down ink flow into a nozzle chamber and to resist back-flow of ink out of the chamber. The capacitive structure defines a voltage potential across the channel width. When a nozzle is fired, the capacitive structure discharges to ground and ink flows through the channel under passive flow conditions. In one embodiment, the ink flows passively for a known time before the capacitive structure is recharged. Once the capacitive structure is activated to recharge and create a voltage potential across the channel, the ink flow is throttled and slowed. As a result, the surge and momentum is reduced and the chamber's initial maximum bulge is not as high as under conventional passive damping schemes. Further, the backlash of the surge is correspondingly reduced resulting in less back-flow. By effectively throttling or damping motion through the nozzle channel, the nozzle chamber achieves a steady-state condition sooner than under passive damping conditions. As a result, a high refill rate occurs for loading the nozzle.

According to another aspect of the invention, the ink includes charge centers responsive to the voltage potential across the capacitive structure. The charge centers are biased to a motionless position, although their momentum may carry them through the channel. The net result of the initial capillary motion forces and the generated capacitive forces is to slow the motion through the capacitive structure (and thus, through the nozzle channel). One known ink-type having charge centers is a polymer-based pigment ink, in which the polymers are charged to stay in solution.

According to another aspect of the invention, alternatively, an inductive damping structure is implemented.

The inductive structure is defined at a nozzle channel to slow down ink flow into a nozzle chamber and to resist back-flow of ink out of the chamber. The inductive structure defines a magnetic field across the channel width. When a nozzle is fired, the inductive structure dissipates allowing ink to flow through the channel under passive flow conditions. In one embodiment, the ink flows passively for a known time before the inductive
structure is reactivated. The inductive structure induces a magnetic field perpendicular to the flow direction. The ink is responsive to the magnetic field. In effect the inductive structure throttles the ink flow and back-flow. As a result, the ink's surge and momentum is reduced and the chamber's initial maximum bulge is not as high as under conventional passive damping schemes. Further, the backlash of the surge is correspondingly reduced resulting in less back-flow. By effectively throttling or damping motion through the nozzle channel, the nozzle chamber achieves a steady-state condition sooner than under passive damping conditions. As a result, a high refill rate occurs for loading the nozzle.

According to another aspect of the invention, the ink is a ferromagnetic ink responsive to the magnetic forces so as to be deterred from moving along the channel.

According to another aspect of the invention, by decreasing ink flow as the chamber fills, the back-flow pressure is reduced once the chamber is full. Thus, the time to achieve a steady-state ink level in the chamber is reduced. Specifically, the time period is reduced between (i) initial achievement of a full chamber with the ink inertia pushing forward to create a bulging meniscus at the nozzle orifice, and (ii) the incremental time thereafter required for the ink flow and back-flow to stabilize and create a steady state ink level.

According to another aspect of the invention, capacitive and inductive structures are implemented together to damp ink flow and back-flow.

One advantage of the invention is that set-up times to achieve a known repeatable ink drop volume are maintained or reduced. Another advantage is that ink flow is effectively maintained for increasingly small ink drop sizes using conventional channel materials. A beneficial effect is that faster printing speeds and improved resolution are achieved for inkjet printers using conventional channel materials and channel geometries. These and other aspects and advantages of the invention will be better understood by reference to the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a conventional inkjet nozzle structure;
Figs. 2a-e are planar views of the nozzle chamber of Fig. 1 at various stages in the nozzle loading process;
Fig. 3 is a time-line of nozzle loading according to a conventional passive-damping method and the active-damping method of this invention;
Fig. 4 is a perspective view of an inkjet nozzle having a capacitive damping structure according to an embodiment of this invention;
Figs. 5a-e are planar views of the nozzle chamber of Fig. 4 at various stages in the nozzle loading process according to an embodiment of this invention;
Figs. 6a-c are respective graphs of firing resistor current, damping device capacitance and nozzle chamber ink volume over time for a nozzle with the capacitive damping structure of Fig. 4;
Fig. 7 is a perspective view of an inkjet nozzle having an inductive damping structure according to another embodiment of this invention; and
Figs. 8a-c are respective graphs of firing resistor current, magnetic field flux, and nozzle chamber ink volume over time for a nozzle with the inductive damping structure of Fig. 7.

DESCRIPTION OF SPECIFIC EMBODIMENTS

Conventional Nozzle and Passive Loading

Fig. 1 shows a conventional inkjet nozzle structure 10 loaded with ink I. In one embodiment a silicon substrate 12 with additional layers defines one or more nozzles. A nozzle 10 receives ink I from a reservoir via a nozzle channel 14. The channel 14 is defined by barriers, including substrate 12, frame 36, nozzle plate 20, and passivation layer 22. The ink flows into a nozzle chamber 16. The nozzle chamber 16 is defined by barriers, including film 18, nozzle plate 20 and passivation layer 22. The nozzle includes additional layers between the substrate 12 and passivation layer 22, including insulative layers 24, 26, another passivation layer 28 and a conductive film layer 30. The conductive film layer 30 defines a firing resistor 32.

In one embodiment the nozzle plate 20 is mounted to a flex circuit 34. In another embodiment the flex circuit forms the nozzle plate 20. According to the flex circuit embodiment for the nozzle plate 20, respective orifices are laser drilled to achieve a precise area, orientation and position relative to the nozzle chamber 16. The nozzle orifice has a uniform diameter for each nozzle. In various embodiments the nozzle orifice is 10-50 microns in diameter. The nozzle 10 is coupled to an ink body 36 which defines an ink reservoir.

Figs. 2a-e depict the nozzle chamber 16 at various times during a conventional passive ink-loading method. Fig. 3 curve a is a time-line of such times. Fig. 2a shows the nozzle chamber 16 at a time t0 corresponding to the firing of an ink drop D. Upon firing capillary action results in ink I flowing through channel 14 (see Fig. 1) into chamber 16. As the ink I flows into the chamber 16, at time t1 (see Fig. 2b and Fig. 3) the ink I surges to a maximum height, (shown as a bulging meniscus). The natural capillary forces then cause the ink to back-flow. At a time t2, the back-flow results in a receding meniscus, See Fig. 2c. The flow and ebb characterized by Figs. 2b and c, respectively, go back and forth with a natural damping occurring until the ink stabilizes at a steady-state ink volume at time t3 as shown in Fig. 2d. The nozzle 10 then is ready to re-fire. At time t4 nozzle 10 is refired as shown in Fig. 2e, restarting the passive loading process of Figs. 2a-d.
According to the invention it is desirable to damp the flow and ebb cycle of Figs. 2b-c and shorten the time between firing (i.e., t₀) and steady-state ink volume (i.e., t₁). By doing so, faster printing speeds are attainable without compromising desired qualities such as repeatable ink drop shape and volume.

Capacitive Control Apparatus and Method

Fig. 4 shows a portion of a nozzle 60, according to an embodiment of this invention. Nozzle 60 similar to nozzle 10, but includes a damping structure for actively controlling the ink loading process. The nozzle 60 includes a channel 14 and chamber 16 which receive ink via capillary action from an ink reservoir (not shown). The damping structure in one embodiment is a capacitive device 62 formed by conductive plates 64, 66 located across opposing sides of the channel 14. Voltages of opposite polarity are defined at the respective plates 64, 66 to create a voltage potential across the channel 14. In effect, the plates 64, 66 and the matter between (e.g., channel 14, ink I and insulative layers 68, 70) define a capacitor. In one embodiment the capacitive structure 62 spans the length of channel 14. In other embodiments the structure 62 extends beyond the channel 14 toward an ink reservoir. In another embodiment, the structure 62 spans a length shorter than channel 14. Preferably, the structure 62 does not extend into the area of chamber 16, particularly the area adjacent to the firing resistor 32. Preferably, coupling forces between the firing resistor 32 and one or both of the plates 64, 66 is avoided. The purpose of the capacitive structure 62 is to throttle the ink movement through channel 14 so as to damp the flow and ebb characteristic of the capillary ink flow action.

Figs. 5a-e show the nozzle 60 at various times during the actively-controlled ink loading process according to an embodiment of this invention. Fig. 3 curve b represents a time-line of the various times represented in Figs. 5a-e. Figs. 6a-c show firing resistor 32 current, structure 62 capacitance, and chamber 16 ink volume at the various times t₀ through t₄. At time t₀ an ink drop D is fired from chamber 16 - see Fig. 5a. As shown in Fig. 6a, the firing resistor current is pulsed causing the resistor to fire. Thus, the ink volume in chamber 16 decreases as shown in Fig. 6c.

In one embodiment, the capacitive structure 62 is activated at the time of firing (see Fig. 5b) creating a voltage potential across channel 14. Also, the natural capillary forces cause ink to flow through channel 14 into chamber 16. The voltage potential across channel 14 acts upon charge centers in the ink to throttle ink flow through channel 14 during the flow cycle.

At time t₁, the chamber 16 reaches a maximum volume of ink I - see Fig. 5b and 6c. Note that this maximum volume is less than that of a comparable nozzle 10 lacking active damping control. (Compare the heights in Figs. 2b and 5b). The natural capillary forces still cause a flow and ebb process, however, the ebb or back-flow also is damped by the capacitive structure 62. As shown in Fig. 5c and 6b, the minimum at time t₂ is not as low as the comparable minimum of Fig. 2c. Further, the time interval between t₂ and t₁ is less than the time interval between t₄ and t₁. The flow and ebb repeats in a generally sinusoidal damping fashion until a steady-state ink volume is achieved at time t₃ - see Figs. 5c and 6. Note that the time interval between t₁ and t₄ is less than the time interval between t₀ and t₃. Further, the time interval between time t₀ and t₃ is less than the time interval between times t₀ and t₃. As a result, the firing period T may be reduced, and correspondingly the firing frequency may be increased, Fig. 3 shows respective firing periods for the conventional nozzle 10 and the nozzle 60 of this invention. Fig. 5e shows the nozzle 60 re-firing, thereby restarting the cycle depicted in Figs. 5a-d and Fig. 6.

To respond to the capacitive forces, it is preferable that the ink I include charge centers or have charge centers induced. Conventional polymer based pigments include charge centers which serve to maintain the polymers in solution. Such charge centers are further utilized according to embodiments of this invention to enable ink flow damping.

According to a specific embodiment a force of 17-20 dynes is applied to ink having a viscosity of 2 centipoise, along a channel 14 having a diameter of approximately 26 micrometers.

Inductive Control Apparatus and Method

Fig. 7 shows a portion of a nozzle 80 according to another embodiment of this invention. Nozzle 80 is similar to nozzle 10 but includes an alternative damping structure for actively controlling the ink loading process. The nozzle 80 includes a channel 14 and chamber 16 which receive ink via capillary action from an ink reservoir (not shown). The damping structure in this embodiment is an inductive device 82 formed by an inductive plate 84 positioned adjacent to channel 14. A current is applied to the inductive device 82 to create a magnetic field perpendicular to the channel 14 length. In the embodiment illustrated, the inductor plate 84 is positioned over the channel 14 inducing a vertical magnetic field. In other embodiments, the plate 84 is positioned along another wall defining channel 14 and generates a magnetic field orienting the channel 14 length runs from the reservoir to the nozzle chamber 16. The channel 14 may be uniform or non-uniform, straight, curved or sectioned.

In one embodiment the inductive structure 82 spans the entire length of channel 14. In other embodiments the structure 82 extends beyond the channel toward an ink reservoir. In another embodiment, the structure 82 spans a length shorter than channel 14. Preferably, the structure 82 does not extend into the area of chamber 16, particularly the area adjacent to the
firing resistor 32. Electromagnetic coupling between the firing resistor 32 and inductive structure 82 is preferably avoided.

The purpose of the inductive structure 82 is to throttle the ink movement through the channel 14 so as to damp the flow and ebb cycles of the capillary ink flow action. Figs. 5a-e show the nozzle 80 at various times during the actively-controlled ink loading method according to an embodiment of this invention. Fig. 3 curve b shows various times t'0 through t'4 compared to the conventional passive loading method times t0 through t4. Figs. 7a-c shows firing resistor 32 current, inductance, and chamber 16 ink volume at the various times t'0 through t'4. At time t'0 an ink drop D is fired from chamber 16-see Fig. 5a. As shown in Fig. 6a, the firing resistor current is pulsed causing the resistor to fire. Thus, the ink volume in chamber 16 decreases as shown in Fig. 6c.

In one embodiment, the inductive structure 82 is activated at the time of firing (see Fig. 6b) creating a magnetic field across channel 14. Also, the natural capillary forces cause ink to flow through channel 14 into chamber 16. The magnetic field acts upon the ink to throttle ink flow through channel 14 during the flow cycle.

At time t'1, the chamber 16 reaches a maximum volume of ink I-see Fig. 5b and 6c. Note that this maximum volume is less than that of a comparable nozzle lacking active dumping control. (Compare the heights in Figs. 2b and 5b). The natural capillary forces still cause a flow and ebb process, however, the ebb or back-flow also is dumped by the capacitive structure 62. As shown in Fig. 5c and 6b, the minimum at time t'2 is not as low as the comparable minimum of Fig. 2c. Further, the time interval between t'2 and t'1 is less than the time interval between t2 and t1. The flow and ebb repeats in a generally sinusoidal dumping fashion until a steady-state ink volume is achieved at time t'3-see Figs. 5c and 6. Note that the time interval between t'1 and t'3 is less than the time interval between t1 and t3. Further, the time interval between t'0 and t'3 is less than the time interval between t0 and t3. As a result, the firing period T may be reduced, and correspondingly the firing frequency may be increased, Fig. 3 shows respective firing periods for the conventional nozzle 10 and the nozzle 80 of this invention. Fig. 5e shows the nozzle 80 re-firing, thereby restarting the cycle depicted in Figs. 5a-d and Fig. 6.

To respond to the magnetic forces, it is preferable that the ink be ferromagnetic. An embodiment of the ferromagnetic ink is described below. According to a specific embodiment a force of 17-20 dynes is applied to ink having a viscosity of 2 centipoise, along a channel 14 having a diameter of approximately 26 micrometers.

Ferromagnetic Ink

The ferromagnetic ink is formed by including ferromagnetic particulate in an ink. Exemplary ink bases include pigment or dye, solvents and water. According to one embodiment a suspension of finely divided ferromagnetic particles in a continuous medium, such as a colloidal solution, is mixed with the ink base to achieve the ferromagnetic ink. The ferromagnetic particles average between 5 and 5000 angstroms in diameter. In a preferred embodiment, the ferromagnetic particles have an average diameter of approximately 100 angstrom and range between 50 and 200 angstrom in diameter.

As the conventional inkjet nozzle is approximately 10-50 microns in diameter, the particles average 50-2000 times smaller than the nozzle diameter. As technology evolves the nozzle size will be smaller. Preferably, the average particle diameter is less than one-fiftieth (1/50) of the diameter of the nozzles, (e.g., less than 500 Angstroms).

In a specific embodiment the colloidal solution is a dispersed ferromagnetic iron lignosulfonate. The solution has a high molecular weight as characteristic of lignosulfonate and an x-ray diffraction pattern as typical of the dispersed ferromagnetic particles. An exemplary solution is sold by the Georgia Pacific Corp. of Bellingham, Washington under the name LIGNOSITE FML. The solution is a thermodynamically stable aqueous colloidal dispersion of ferromagnetic iron in lignosulfonate. The dispersion does not exhibit significant settling out, even upon standing for prolonged periods. The solution can be dried and redissolved without separation of the iron from the lignosulfonate and without losing the magnetic properties. Such characteristics occur because the lignosulfonate is firmly attached to the magnetic particles by chemical bonds and is not separable by non-destructive chemical processes.

The LIGNOSITE FML solution sold as dark brown liquid of approximately 32% solids and a Brookfield viscosity of 29 cps at 25°C. In a working embodiment the LIGNOSITE FML is mixed a black pigment ink base at a ratio of 1 part solution to 2 parts conventional black pigment ink base. For a black ink, in one embodiment a carbon black pigment base ink is used. An exemplary embodiment of such base has a viscosity of 4.6 cps at 25°C and a surface tension of 55.9 dynes/cm. The ink has a calculated saturation magnetization of 30 Gauss and an iron content of approximately 3%.

Meritorious and Advantageous Effects

One advantage of the invention is that set-up tunes to achieve a known repeatable ink drop volume are maintained or reduced. Another advantage is that ink flow is effectively controlled for increasingly small ink drop sizes using conventional channel materials. A beneficial effect is that faster printing speeds and improved resolution are achieved for inkjet printers using conventional channel materials and channel geometric relations.

Although a preferred embodiment of the invention has been illustrated and described, various alternatives,
modifications and equivalents may be used. Therefore, the foregoing description should not be taken as limiting the scope of the inventions which are defined by the appended claims.

Claims

1. A method for controlling ink-loading of an inkjet nozzle (60,80) between sequential nozzle firings, the nozzle having a channel (14) leading to a chamber (16), ink flowing from a reservoir through the channel into the chamber, the nozzle firing an ink drop (D) from the chamber, the drop having a first volume, the method comprising the steps of:

- flowing ink (I) through the channel (14) into the chamber (16) after the nozzle (60,80) fires;
- activating a damping device (62,82) located about the channel before nozzle chamber capacity reaches the first volume; and
- actively damping ink flow through the channel in the vicinity of the damping device as nozzle capacity approaches the first volume.

2. The method of claim 1 in which the damping device is a capacitive device (62) and the ink comprises charge centers, wherein the step of actively damping comprises creating a voltage potential across a width of the channel, movement of the ink charge centers being slowed by the voltage potential.

3. The method of claim 1 in which the damping device is an inductor (82) and the ink is ferromagnetic, and wherein the step of actively damping comprises creating a magnetic field (M) generally perpendicular to a length of the channel, movement of the ferromagnetic ink being slowed by the magnetic field.

4. An inkjet nozzle (60,80) with damped ink flow during nozzle loading, the nozzle receiving ink from a reservoir and ejecting ink onto print media, comprising:

- a first barrier (12) that defines a nozzle chamber (16);
- a second barrier (12) that defines a nozzle channel (14);
- a firing resistor (32) for ejecting ink (I) from the nozzle chamber, wherein ink from the reservoir is received into the nozzle chamber via the nozzle channel;
- an inductor (82) adjacent to the channel and receiving a current signal, the inductor defining a magnetic field (M) across the channel in response to the current signal, the magnetic field acting upon the ink to damp ink movement through the channel.

5. An inkjet nozzle (60,80) with damped ink flow dur-
**DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td>IBM TECHNICAL DISCLOSURE BULLETIN, vol. 27, no. 3, August 1984 NEW YORK, US, pages 1731-1732, ANONYMOUS 'Ink Jet Printer Head' * the whole document *</td>
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The present search report has been drawn up for all claims.

**Examiner**
Meulemans, J-P

**Place of search**
The Hague

**Date of completion of the search**
29 April 1996

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