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(54) Method and apparatus for controlling of an ink jet printer.

(57) An ink jet printing machine and method of printing in which a print head (10) is switched from the energized condition to the de-energized condition without emitting undesired writing fluid therefrom. Means (10, 30) is provided for projecting a flow of writing fluid in the energised condition and for preventing the flow of fluid being projected in the de-energised condition. Switching means (34, 36) switches the projecting means from the energised to the de-energised condition with no undesired writing fluid by emitted and ingestion of air, preferably by controlling the pressure of the writing fluid in the head (10) so that it is reduced in two steps.

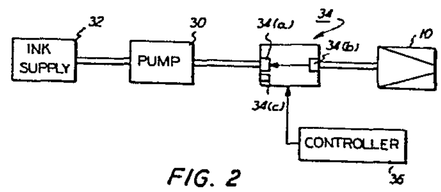

FIG. 2

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AN INK JET PRINTING MACHINE AND METHOD

This invention relates generally to ink jet printing, and more particularly concerns switching an ink jet print head from the energized state to the de-energized state without emitting undesired writing fluid therefrom.

In general, ink jet printing employs a writing fluid or ink which is forced under pressure through a small nozzle to form a jet. The jet is vibrated so as to form pressure waves which cause the jet to break up into a stream of droplets of substantially uniform size and spacing at a well defined distance from the nozzle. A voltage is applied to an electrode surrounding the break up point of the jet. This induces an electrical charge of a specific pre-determined magnitude on the forming drop. The charge is retained by the drop throughout its flight to the recording sheet. The stream of drops pass through an electrostatic field formed by a fixed high voltage across a pair of horizontal deflection plates. Since the charge in each drop is individually controlled, a drop can be deflected vertically by a desired amount. Thus, the drops are deflected vertically from bottom to top and one column of dots and/or spaces is referred to as a scan. If, in forming a character, a particular space in a scan is to be left blank, it is blanked by leaving the drops uncharged. These undeflected drops are intercepted by a gutter and recycled to the ink reservoir. As drops are deflected vertically, the print head or the recording sheet are moved at a substantially constant speed. Thus, drops are deposited on the recording sheet at the appropriate positions within a raster area to form the desired character.

One of the problems associated with an ink jet printing machine occurs during start up and shut down of the system. It is particularly difficult to shut down a continuous stream of writing fluid or a stream of drops adequately. If the stream is stopped too slowly, fluid may miss the gutter and contaminate the printing system causing electrical and mechanical failures. If depressurization of part of the ink system immediately upstream of the nozzle is not damped sufficiently, the resulting pressure undershoot causes air to be ingested by the nozzle resulting in system failure. Thus, it is highly desirable to control the pressure applied to the ink so as to optimize switching from the energized condition to the de-energized state.

Various approaches have been devised to improve ink jet printing machines.

US-A-3924974 describes a fluid jet device formed of a tube having a curvalinear cross-section comprising two bow-like shaped sections, a flat member disposed along the axis of the tubes spanning opposite walls thereof along the major diameter to form a cord of the two bow-like shaped section, and a nozzle joined to the tube. The flat member divides the tube into two chambers for fluid with each having a cross-sectional area enclosed by a bow-like shaped section. The tube is made from a magneto-stricture material. When a circumferential magnetic field is applied to the tube, the tube contracts reducing the volume thereof to eject a jet of fluid through the nozzle.

US-A-3945020 discloses a liquid jet recorder in which nozzles project a recording liquid from supply receptacles through the use of pumps. The recording liquid passes between control electrodes. Pressure regulators are interposed between the nozzles and pumps. Suction pads are provided for cleaning the electrodes.

US-A-3950761 describes an electromagnetically actuated plunger driven against the bottom portion of an elastic material comprising the bottom of an ink storage. This pressurizes the ink held in storage, thereby conducting the ink to the tip of the nozzle under pressure.

US-A-4005435 discloses a liquid jet droplet generator including a pump which furnishes pressurized ink to a nozzle contacting a tapered horn having a piezoelectric transducer associated therewith. Excitation of the transducer produces periodic pressure variations to form droplets of a thicker viscosity ink than heretofore utilized.

US-A-4089007 describes an ink jet printing system having a primary orifice and a secondary orifice of a binary actuated pressure transducer. The pressure regulator is interposed between an ink pump and nozzle array. The primary orifice furnishes ink at a pressure below the minimum with both orifices, together, supplying ink at a pressure above the desired maximum. The pressure sensor controls the solenoid to open the valve at the minimum pressure and to close the valve at the maximum pressure, thus cycling between the two conditions.

US-A-4171527 discloses an ink jet printing machine in which a circuit detects contamination of the charge electrodes or deflection plates by ink. The ink jet head is shut-off in response to contamination being sensed.

US-A-4184168 describes an ink jet head in which a high voltage pulse is applied to a piezoelectric transducer. The transducer is deformed pressurizing ink in the chamber and an ink jet is discharged through a nozzle. A comparator compares video signal with a reference voltage to deliver a high level output when the video signal is equal to or higher than the reference and a low level output when the video signal is lower than the reference voltage. A pulse synchronization circuit receives the output from the comparator and delivers an output pulse in synchronism with a printing sync pulse when a high or low level signal is received from the comparator. A sample-hold circuit holds the peak value of the video signal. The output of the sample-hold circuit is applied to a high-voltage energization circuit which develops the high voltage pulse. The output pulse from the synchronization circuit resets the sample-hold circuit.

An ink jet printing machine in accordance with the present invention, is characterised by means for switching said projecting means from the energized conditon to the deenergized conditon with no undesired writing fluid being emitted therefrom and ingestion of air therein.

A method of ink jet printing according to the invention is characterised by the steps of energizing a print head to project writing fluid therefrom, deenergizing the print head to prevent the projection of printing fluid therefrom, and switching from said step of energizing to said step of de-energizing with no undesired writing fluid being emitted therefrom and ingestion of air therein.

In order that the invention may be more readily understood, reference will now be made to the accompanying drawings in which:

Figure 1 is a schematic elevational view illustrating an exemplary ink jet printing machine incorporating the features of the present invention therein;

Figure 2 is a schematic elevational view depicting the control system for preventing emission of undesired writing fluid from the nozzle of the Figure 1 printing machine;

Figure 3 is a schematic elevational view showing one embodiment of the Figure 2 control system;

Figure 4 is a schematic elevational view illustrating another embodiment of the Figure 2 control system;

Figure 5 is a graph depicting one method of de-energizing the Figure 1 printing machine; and

Figure 6 is a graph depicting another method of de-energizing the Figure 1 printing machine.

As shown in Figure 1, the ink jet printing machine employs a nozzle. Nozzle 10 projects a jet of writing fluid or ink therefrom. The ink is forced through nozzle 10 under pressure to form the jet. A transducer, e.g. piezoelectric crystal 12, associated with nozzle 10, vibrates the ink within the cavity of nozzle 10 at a fixed ultrasonic frequency. The pressure waves cause the jet of ink to break up into a stream of droplets at a fixed distance from the exit of nozzle 10. A voltage source 14 applies a voltage of a predetermined magnitude to electrodes 16. Electrodes 16 are positioned at the point wherein the jet of ink emitted from nozzle 10 breaks up into droplets. In this way, the voltage applied to the electrodes induces an electrical charge of a specific, predetermined magnitude on the forming drop. The voltage applied to electrode 16 by voltage source 14 is controlled by a character data input. Thus, the magnitude of the voltage is determinative of the specific character being formed on the recording sheet. Next, the charged droplets pass through a pair of parallel plates 18. Plates 18 are electrically biased to a fixed voltage level. This produces a fixed high voltage across plates 18 resulting in an electrostatic field therebetween. Inasmuch as the charge on each drop is controlled individually, the drops deflect a specified amount depending upon the selected charge thereon and the electrostatic field through which they pass. The drops are deflected vertically onto recording sheet 20. Preferably, recording sheet 20 is a sheet of paper. A series of drops form a column in the character. One column of dots and/or spaces is the scan. If in forming a character, a particular space in the scan is to be left blank, or white, the drops remain uncharged. Inasmuch as the drops are not charged,they remain undeflectedby deflection plates 18 and are received by gutter 22. The unused ink passes into reservoir 24 for subsequent recycling. From reservoir 24, the ink passes through filter screen 26 and into ink supply 28. Pump 30 advances the ink from supply 28 back to nozzle 10. Piezoelectric crystal 12 is electrically excited by a crystal driver circuit 32.

In order to prevent extraneous or undesired ink flow when the printing machine is switched from the energized state to the de-energized state, the ink in the nozzle must be depressurized. Preferably, the pressure is initially reduced slowly to the pressure corresponding to the minimum captive velocity of the jet of ink by gutter 22, and rapidly for the rest of the depressurization cycle. Inasmuch as the rapid part of the depressurization is started at a much lower pressure than was heretofore utilized, the pressure undershoot is minimized. The first reduction of ink pressure in the nozzle may be achieved by controlling the supply of ink thereto. The control system for regulating the pressure of the ink being furnished to the nozzle is depicted in Figure 2.

Turning now to Figure 2, a portion of the Figure 1 printing machine is shown thereof. Pump 30 advances ink from ink supply 28 through valve 34 to nozzle 10. When the printing machine is energized, i.e. nozzle 10 emits a fluid jet therefrom, inlet port 34(a) of valve 34 is coupled to outlet port 34(b). Under these circumstances, ink passes through valve 34 to nozzle 10. Controller 36 regulates valve 34. Thus, when the printing machine is energized, controller 36 activates valve 34 such that inlet port 34(a) is coupled to outlet port 34(b). Pump 38 is connected to inlet port 34(a) and nozzle 10 is connected to outlet port 34(b). Venting port 34(c) is closed.

Referring now to Figure 3, there is shown one embodiment of controller 36. As depicted thereat, when the printing machine is de-energized, controller 36 activates valve 34 such that outlet port 34(b) is coupled to venting port 34(c). Inasmuch as inlet port 34(a) is closed, ink will no longer be furnished to outlet port 34(b). Controller 36 monitors the pressure in the conduit coupled to outlet port 34(b). Pressure tranducer 38 converts the measured pressure to voltage. By way of example, pressure transducer 38 may be a strain gauge diaphragm which detects constant and high frequency pressure changes. One suitable type of pressure transducer is a Kulite semiconductor. The output from pressure transducer 38 is amplified by instrumentation amplifier 40. The output voltage from amplifier 40 is approximately 0.16 volts/psi. The output from amplifier 40 is compared with a reference voltage corresponding to a reference pressure by comparator 42. When the output from amplifier 40 is equal to or less than the reference voltage or pressure, the comparator generates a signal to open port 34(c), thereby venting the system to atmosphere. By way of example, the operating pressure of the printing system is about 40 psi. After pump 30 has been decoupled from nozzle 10 by switching outlet port 34(b) of valve 34 from inlet port 34(a) to venting port 34(c), the pressure decays to about 10 psi in about 17 milliseconds. Inasmuch as 10 psi is the reference pressure, comparator 42 now generates a signal opening port 34(c). The pressure now decays rapidly from 10 psi to about 0 psi without any dribble or extraneous undesired ink flow being emitted from nozzle 10. From 40 psi to 10 psi, a flow of ink is emitted from nozzle 10 which is captured by gutter 22. It is clear that this control scheme may be employed for an array of nozzles in addition to a single nozzle. In this way, each nozzle of the array is selectively actuated and deactuated without one nozzle remaining on while the next successive nozzle is energized.

Referring now to Figure 4, there is shown another embodiment of controller 36. As depicted therein, controller 36 includes a timing circuit 44. When nozzle 10 is de-energized, timing circuit 44 controls valve 34 such that outlet port 34(b) is coupled to closed venting port 34(c). Inasmuch as the pressure decay as a function of time in the specified system is known, the timing circuit opens port 34(c) to vent to atmosphere after the elapse of a specified time delay. For example, if the system operates at 40 psi, the line pressure will decay to about 10 psi after an elapse of 17 milliseconds. Thus, timing circuit 44 will open port 34(c) to vent to atmosphere after the elapse of 17 milliseconds from supply termination. In this manner, the jet of ink will be captured by gutter 22 from 40 psi to about 10 psi and, thereafter, the pressure will decrease rapidly from 10 psi to 0 psi with little or no undershoot. This significantly prevents the occurrence of dribble or the emission of undesired ink from nozzle 10, as well as preventing air ingestion through the nozzle.

Referring now to Figure 5, there is shown a graph of ink pressure as a function of time. As shown thereat, the system is initially at operating pressure, i.e. 40 psi. When switching from nozzle energization to de-energization, the ink supply to nozzle 10 is shut-off. Thereafter, the pressure in nozzle 10 will decay to the reference pressure, i.e. 10 psi.

When the reference pressure is reached, the nozzle is vented to atmosphere producing a rapid depressurization of the system. The time delay between closing the ink supply to the nozzle and venting the system to atmosphere is determined by either monitoring the pressure until it reaches the desired pressure or by knowing the time required to reach the desired pressure and utilizing a timing circuit to produce this delay.

An alternate approach, as shown in Figure 6, requires that the ink supply pressure be initially reduced to a lower pressure. The ink supply to the nozzle is then shut-off. When the reference pressure is reached, the nozzle is vented to atmosphere.

In recapitulation, the present invention controls switching a nozzle from energization to de-energization without projecting undesired writing ink therefrom. The nozzle maintains a jet of ink from the operating pressure to the reference pressure. This depressurization occurs slowly and permits the gutter to capture this jet of ink. Once the reference pressure is achieved, the system is vented to atmosphere reducing the pressure almost instantaneously. Inasmuch as the pressure is reduced rapidly, the transient undershoot is minimal and no undesired ink droplets or dribble occurs. In this way, successive nozzles of an array of nozzles may be switched from the energized state to the de-energized state without producing undesired ink flow and contamination. It is, therefore, evident that there has been provided in accordance with the present invention an ink jet printing machine that optimizes switching of successive nozzles from the energized state to the de-energized state without any extraneous writing ink being emitted from the respective nozzle.

Claims

1. An ink jet printing machine, including:

means (10, 30), in the energized condition, for projecting a flow of writing fluid therefrom, and, in the de-energized condition, for preventing the flow of writing fluid from being projected therefrom; characterised by

means (34, 36) for switching said projecting means (10) from the energized condition to the de-energized condition with no undesired writing fluid being emitted therefrom and ingestion of air therein.

2. A printing machine according to claim 1, wherein said switching means (34, 36) includes means (36) for controlling the pressure of the writing fluid in said projecting means (10).

3. A printing machine according to claim 2, wherein said controlling means (36) reduces the pressure in said projecting means to a first pressure over a first time period and a second pressure over a second time period with the first time period being greater than the second time period.

4. A printing machine according to claim 2 or 3, wherein said controlling means (36) includes:

means (38) for sensing the pressure in said projecting means;

means (42) for comparing the sensed pressure with a reference pressure; and

means (34c), in response to the difference between the sensed pressure and the reference pressure, for regulating the pressure in said projecting means (10).

5. A printing machine according to claim 2 or 3, wherein said controlling means (36) includes:

means (34) for adjusting the supply of writing fluid being furnished to said projecting means (10); and means (44), in response to the elapse of a selected period of time, for reducing the pressure in said projecting means (10).

6. A printing machine according to claims 1 or 3, wherein said projecting means (10, 30) includes:

at least one nozzle (10); and

means (30) for furnishing a pressurized writing fluid to said nozzle.

7. A method of ink jet printing, characterised by the steps of:

energizing a print head to project writing fluid therefrom;

de-energizing the print head to prevent the projection of printing fluid therefrom; and

switching from said step of energizing to said step of de-energizing with no undesired writing fluid being emitted therefrom and ingestion of air therein.

8. A method according to claim 7, wherein said step of switching includes a step of controlling the pressure of the writing fluid in the print head, preferably by reducing the pressure in the print head to a first pressure over a first time period and to a second pressure over a second time period with the first time period being greater than the second time period.

9. A method according to claim 8 wherein said step of controlling includes the steps of:

sensing the pressure in the print head;

comparing the sensed pressure with a reference pressure; and

regulating the pressure in the print head in response to the difference between the sensed pressure and reference pressure.

10. A method according to claim 8 wherein said step of controlling includes the steps of:

adjusting the supply of writing fluid being furnished to the print head; and

reducing the pressure in the print head a selected period of time after said step of adjusting.

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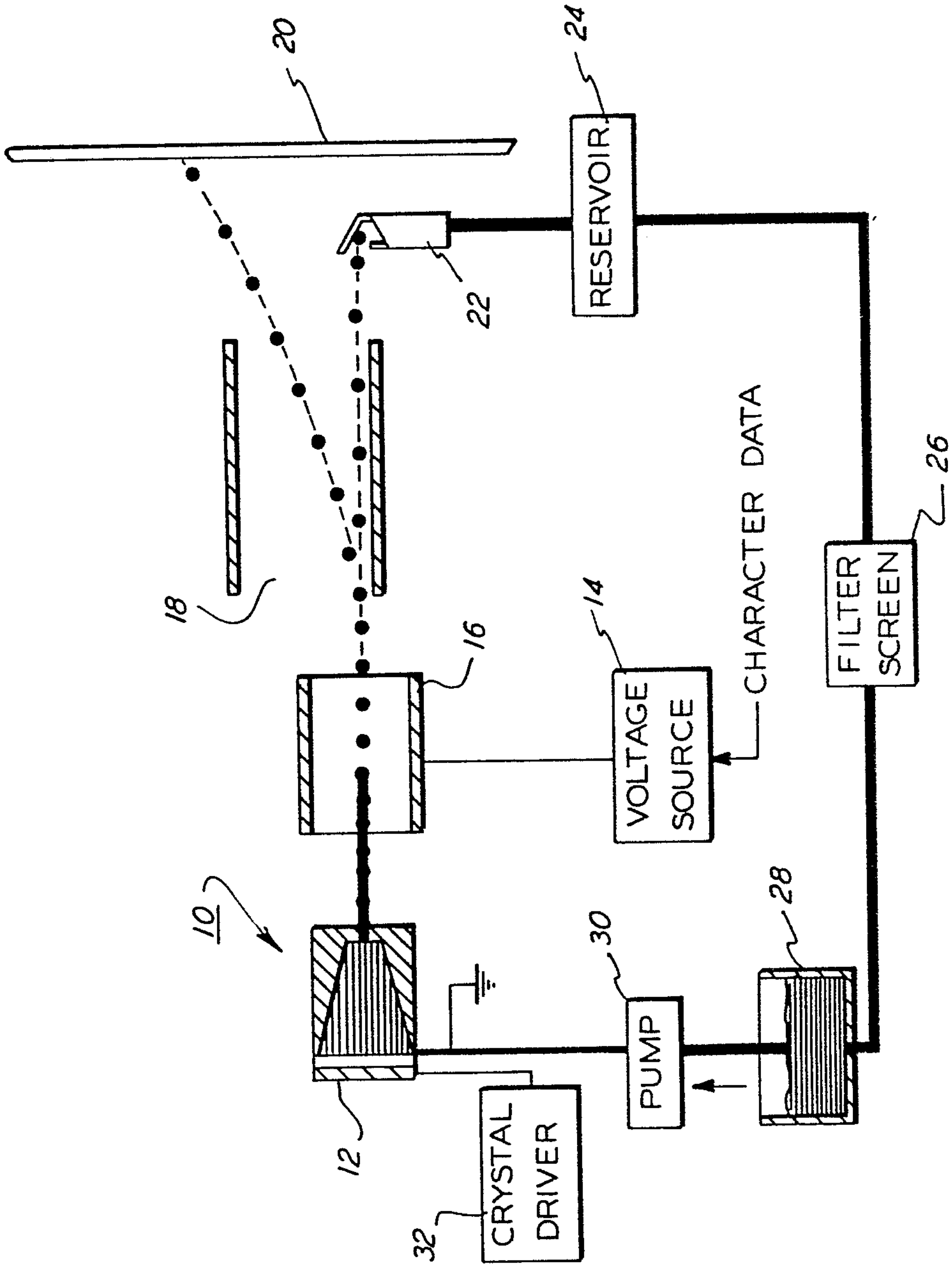

FIG. 1

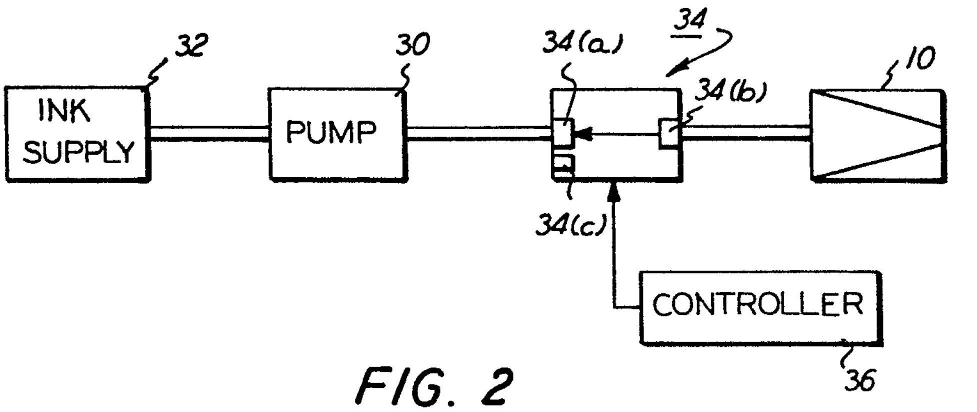

FIG. 2

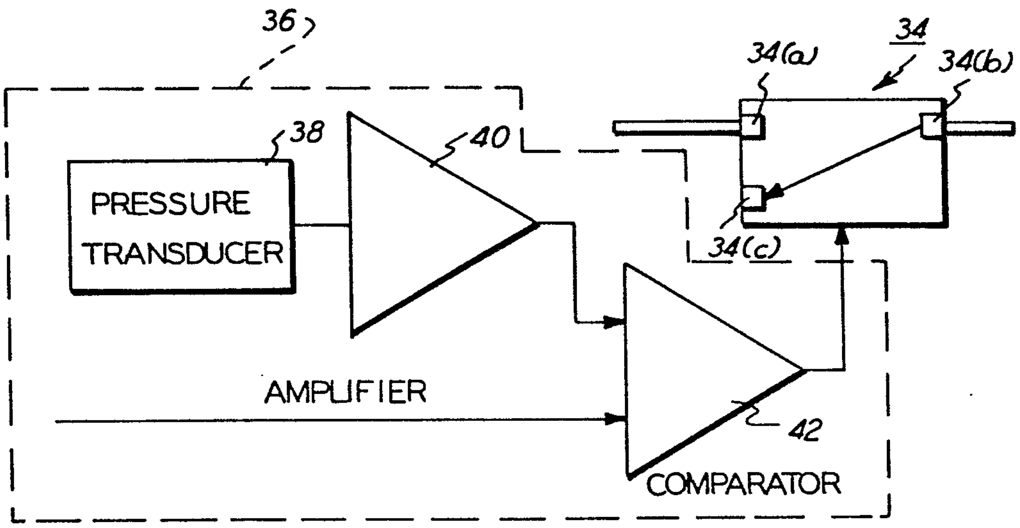

FIG. 3

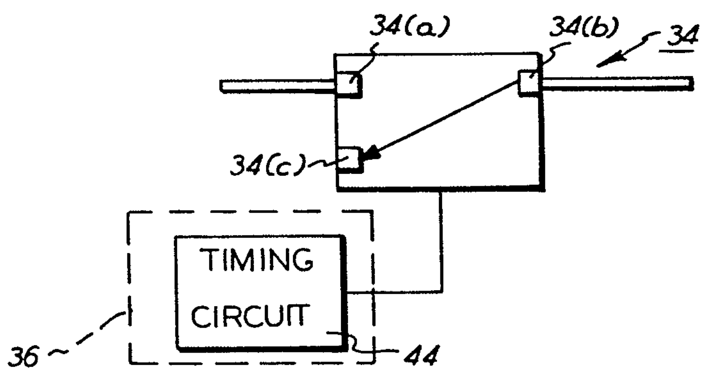

FIG. 4

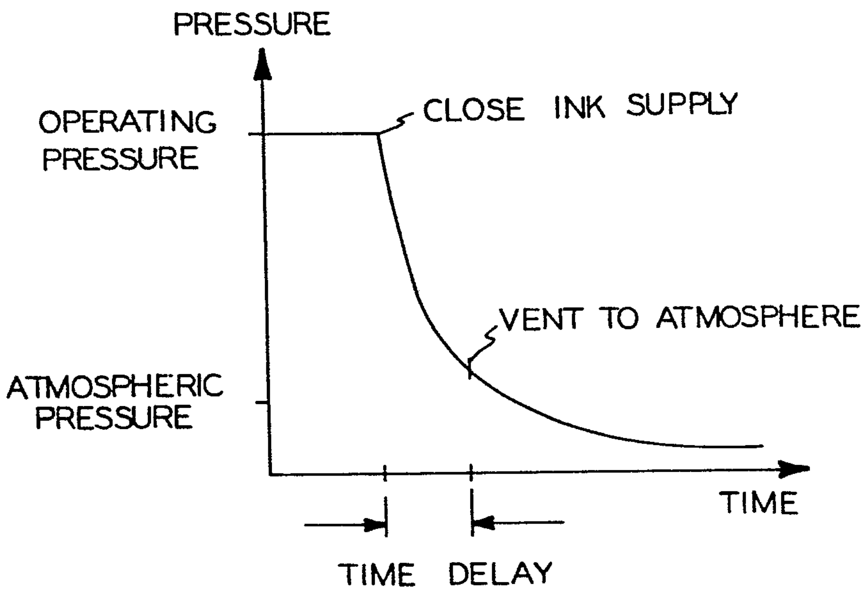
PRESSURE
OPERATING PRESSURE
CLOSE INK SUPPLY
VENT TO ATMOSPHERE
ATMOSPHERIC PRESSURE
TIME
TIME DELAY

FIG. 5

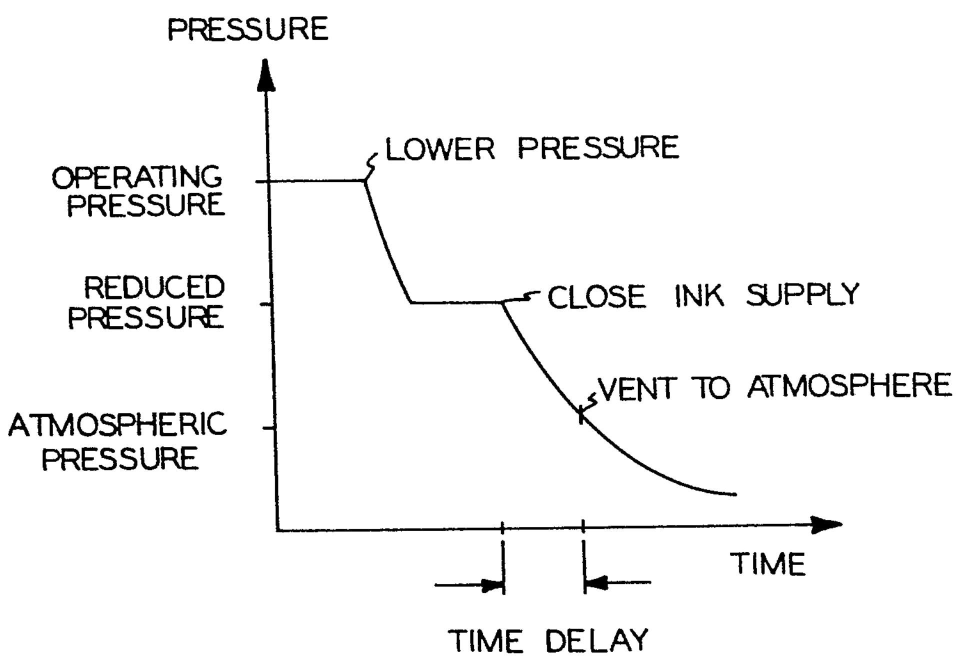
PRESSURE
LOWER PRESSURE
OPERATING PRESSURE
REDUCED PRESSURE
CLOSE INK SUPPLY
VENT TO ATMOSPHERE
ATMOSPHERIC PRESSURE
TIME
TIME DELAY

FIG. 6