

PATENTS ACT 1977

Agents' Reference: Q7405GB-H/JCC/ac

DESCRIPTION OF INVENTION

Title: "Ink Jet Recording Apparatus"

THIS INVENTION relates to an ink jet recording apparatus, and more particularly to an ink jet recording apparatus of the continuous jet type wherein ink is jetted continuously from a nozzle of an ink jet recording head.

Various ink jet recording apparatus are conventionally known and practically used. One of such conventional ink jet recording apparatus is of the continuous jet type wherein ink is jetted continuously from an ink jet recording head. An exemplary one of such conventional continuous jet type ink jet recording head is shown in Figure 8. Referring to Figure 8 the continuous jet type ink jet recording head shown includes an ink bottle 91 in which ink is accommodated, an ink pump 92 for applying a pressure to ink from the ink bottle 91 and sending out the thus pressurized ink, an ink tube 93 for supplying ink from the ink pump 92 therethrough, a nozzle 94 having a circular orifice of a very small diameter, an ink electrode 95 for holding the potential of ink in the nozzle 94 at a ground level, a vibrating element 96 in the form of a piezoelectric _____

vibrating element mounted on the nozzle 94, a vibrating element driving vibrator 97 for applying an exciting signal to the vibrating element 96, a controlling electrode 98 having a circular opening or a slit-like opening coaxial with the nozzle 94 for receiving a controlling signal to control charging of a jet of ink, a grounding electrode 99 disposed in front of the controlling electrode 98 and grounded itself, a knife edge 100 mounted on the grounding electrode 99, a deflecting high voltage dc power source (hereinafter referred to as deflecting power source) 101, and a deflecting electrode 102 connected to the deflecting power source 101 for cooperating with the grounding electrode 99 to produce therebetween an intense electric field perpendicular to an ink jet flying axis to deflect a charged ink drop to the grounding electrode 99 side. The thus deflected charged ink drop is flown to a record medium 104 wrapped around a rotary drum 103.

In such conventional continuous jet type ink jet recording apparatus, ink pressurized by the ink pump 92 is introduced by way of the ink tube 93 into the nozzle 94, at which a jet of the ink is formed from the orifice thereof. The ink jet is disintegrated into a train of ink drops with a spontaneous disintegrating frequency

which depends upon a diameter and a flow rate of the ink jet and physical properties of the ink. In this instance, if the exciting frequency of the vibrating element 96 mounted on the nozzle 94 is set to a value at or around the spontaneous disintegrating frequency, then disintegration will be synchronized with excitation of the vibrating element 96, and consequently, ink drops of a very uniform size are produced in accordance with the exciting frequency.

Ink drops disintegrated in this manner are charged, upon separation from the ink jet, by electrostatic induction by way of an integrating circuit composed of an electric resistance R_j of the ink jet and an electrostatic capacitance between the ink jet and the controlling electrode 98. Thus, if the controlling signal is a rectangular wave having an amplitude ϕ_c , then a potential of an ink drop immediately before disintegration is given by

$$\phi_j = \phi_c(1 - \exp(-t/C_j R_j))$$

If the uniform ink drops separated from the ink jet are charge modulated in accordance with a controlling signal (recording pulse signal) synchronized in phase with an exciting signal, then such charged ink drops will be deflected to the grounding electrode 99

side by an action of the deflecting electric field and cut by the knife edge 100 while only non-charged ink drops are allowed to advance straightforwardly and pass by the knife edge 100 so that they form dots of ink on the record medium 104 wrapped around the rotary drum 103.

Now, if the exciting frequency (disintegrating frequency) is set to f_d and an ink jet is pulse width modulated by a frequency of f_d/n , then a picture image of n gradations with a controlled dot diameter can be recorded at the frequency of f_d/n .

In the conventional continuous jet type ink jet recording apparatus described above, the exciting signal to the vibrating element 96 and the controlling signal (recording pulse) to the controlling electrode 98 must be synchronized with each other maintaining a certain optical phase relationship. In particular, while an ink dot is produced in synchronism with an exciting signal, a timing at which an ink jet disintegrates into an ink drop is varied delicately during one period of an exciting signal by a variation of parameters such as a temperature, an ink pressure and physical properties of ink. If such timing of disintegration and the controlling signal (recording pulse) are displaced in

phase from each other, then the electric resistance R_j of an ink jet presents a very high value immediately before disintegration, and consequently, an edge of the controlling signal (recording pulse) comes within a region (hereinafter referred to as forbidden region) where the resistance is very high. Accordingly, charging of an ink drop takes place but incompletely, and an incompletely charged ink drop is produced. If an incompletely charged ink drop is produced, then it is impossible to individually control ink drops accurately. As a result, a spot-like noise is produced mainly at a highlight portion of a recorded picture image.

A technique of merely synchronizing an exciting signal and a controlling signal (recording pulse) with each other is disclosed, for example, in Japanese Patent Laid-Open Application No. 62-225363, Japanese Patent Laid-Open Application No. 63-264361 and so forth.

Meanwhile, a method of determining an optimum phase between an exciting signal and a controlling signal (recording pulse) is disclosed, for example, in U. S. Patent No. 4,839,665, wherein an ink jet is charged either in accordance with a probe pulse having a smaller width than a period ($1/f_s$) of an exciting signal or another probe pulse having a pair of pulses having an

equal amplitude and an equal pulse width within one period of such exciting signal but having the opposite polarities to each other while changing the phase of the probe pulse, and a current which flows together with an ink jet (such current will be hereinafter referred to as jet current) is successively measured to find out an optimum phase from measured values of the jet current. However, such jet current is a very low current (10 to 100 nA) and a current source is exposed to various noises. With an actual machine, it is difficult to shield such current source from external noises. Particularly, noises (hums) from a commercial power supply of, for example, ac 100 V matter.

A method of measuring a jet current is also disclosed in U.S. Patent No. 4,835,665 mentioned above wherein a current detecting resistor is interposed between an ink electrode and the ground to convert a jet current into a voltage. Another method wherein an ink electrode is connected to a virtual grounding point of an operational amplifier constituting a current to voltage converter is disclosed in No. PCT/US88/03311. The two methods are advantageous in that, where a continuous jet type ink jet recording apparatus includes a plurality of nozzles like a color ink jet printer, a

jet current can be detected independently for each of the nozzles. However, in order to introduce all of jet currents to a current detector, entire ink supplying systems from ink bottles to nozzles including ink pumps must be kept in an electrically isolated condition. Further, each of such ink supplying systems includes a very long ink tube and so forth and accordingly makes a very harmful noise source. Accordingly, it is difficult to measure a jet current at a high S/N ratio.

A further method of detecting a jet current flowing between a grounding electrode and a deflecting electrode is disclosed in U.S. Patent No. 4,839,663 mentioned hereinabove. The method is superior to the method which makes use of an ink electrode in that a jet current can be measured at a high S/N ratio with low noises. However, it has the following problems that:

- (1) while measurement is easier on the grounding electrode side to which no high voltage is applied, in such instance, the grounding electrode, which is soiled with waste liquid, must be kept in an isolated condition; and
- (2) even in a continuous jet type ink jet recording apparatus such as a color ink jet printer which includes a plurality of nozzles, only one deflecting electrode

and only one grounding electrode are provided, and in this instance, since waste liquid from the nozzles come to the single grounding electrode, a jet current cannot be measured independently for each of the nozzles.

Also a method is disclosed in U.S. Patent No. 4,839,665 mentioned hereinabove wherein an electrically isolated conductive ink catcher is provided in front of a grounding electrode and a deflecting electrode, and a current detecting resistor is interposed between the conductive ink catcher and the ground to detect a jet current. While the method is better than the two methods described above, since a signal source has a high impedance of 10^9 to $10^{12} \Omega$, also the current detecting resistor must be high in resistance, which makes it easy to admit noises. Consequently, measurement of a jet current at a high S/N ratio cannot be achieved. Thus, an alternative measuring method using an ac technique, that is, a method wherein a probe pulse is amplitude modulated and a jet current is detected by means of a narrow-band amplifier, is disclosed in U.S. Patent No. 4,839,665 mentioned above. This method, however, still has a problem that a circuit system is complicated and expensive and the stability is low because an amplitude modulated probe pulse is used.

As described above, an ink jet printer such as a color ink jet printer normally includes a plurality of nozzles. In particular, where the conventional continuous jet type ink jet recording apparatus described hereinabove with reference to FIG. 19 is constructed as such ink jet printer, it includes a plurality of such continuous jet type ink jet recording heads as described above. In this instance, the continuous jet type ink jet recording heads are provided independently of each other while the grounding electrode 99, knife edge 100, deflecting power source 101 and deflecting electrode 102 are provided commonly to the ink jet recording heads. In such ink jet printer, the nozzles 94 of the ink jet recording heads are disposed in line either in an axial direction (hereinafter referred to as drum axial direction) or in a circumferential direction (hereinafter referred to as drum circumferential direction) of the rotary drum 103.

By the way, since the nozzles 94 are different in directions of axes of ink jets therefrom (nozzle axes) and in flying speeds of such ink jets, they must be adjustable in registration. However, where flying speeds of ink jets are different, even if a controlling signal is received simultaneously by the controlling

electrodes 98, times required for ink jets to reach a surface of the rotary drum 104 are different from each other. Consequently, the ink jets will be flown to displaced positions.

Adjustment in alignment of such nozzles 94 where they are arranged in line in an axial direction of the rotary drum 103 includes, as adjustment in a drum axial direction, mechanical leftward and rightward adjustment (in the drum axial direction) of the nozzles 94 and time lag adjustment of recording picture element data for the nozzles 94 (by a distance between the nozzles 94), and includes, as adjustment in a drum circumferential direction, time lag adjustment of recording picture element data for the nozzles 94.

Adjustment in registration in a drum circumferential direction is conventionally achieved by either of the following two registration adjusting mechanisms:

- (1) According to such registration adjusting mechanism as disclosed, for example, in Kent Bladh, Report 1, Dept. Electr. Meas., Lund Inst. Tech., 1982, pp. 112-114 or in Japanese Patent Laid-Open Application No. 62-225963, delay circuits having delay times adjustable independently of each other are provided for nozzles for

four different colors (C (cyan), M (magenta), Y (yellow) and BK (black)). Each of the delay circuits is composed of a serial-in/serial-out type shift register and an oscillator having a variable vibration frequency and having an output to be supplied as a shift clock signal to the shift register. A time required until picture image data are outputted from the shift register after having been inputted to the shift register, that is, a delay time, can be adjusted by varying an output frequency of the oscillator.

(2) According to the other registration adjusting mechanism disclosed in Japanese Patent Laid-Open Application No. 62-33647, Japanese Patent Laid-Open Application No. 62-68761 and so forth, buffer memories (line buffers) are provided into which picture image data can be written at different addresses variable independently for four colors (C, M, Y and BK). Four color data are written into the buffer memories at different addresses which are displaced from each other by distances corresponding to distances between them, and reading out (printing) of data from the buffer memories is performed simultaneously for the four colors to compensate for the displacements of the nozzles.

With the first registration adjusting mechanism

described above, if it is intended to raise the resolution for registration adjustment to assure a wide range of adjustment, then the oscillator frequency of the oscillator must be raised and the number of bits must be increased. Accordingly, a shift register which is high in number of bits and can operate at a high speed (for example, a several hundreds to several kilobits shift register which operates by several megahertz) is required. However, such shift register is expensive and is not readily available. Accordingly, a plurality of shift registers which do not have a sufficiently large number of bits must be connected in series in use.

Further, since the resolution in time is a reciprocal number to an oscillation frequency of the oscillator, if such frequency varies, then the resolution in registration adjustment is varied. Accordingly, in case registration adjustment is performed with a higher oscillation frequency so that a resolution for registration adjustment necessary at a minimum frequency may be assured, the resolution in registration adjustment may be unnecessarily high.

On the other hand, with the second registration adjusting mechanism described above, four color (C, M, Y

and BK) picture data are written into the buffer memories at different addresses, and they are read out, upon printing, in synchronism with a picture element recording clock. Accordingly, a resolution in registration adjustment is a reciprocal number to a frequency of a picture element recording clock signal and is very low on a recording face because it is provided by recording dots on the recording face. Accordingly, the second registration adjusting mechanism is very low in resolution in registration adjustment and accordingly is not suitable for a high resolution printer.

In our co-pending U.K. Patent Application No. 9125474.8 (GB 2251710) there is described and claimed an ink jet recording apparatus, characterised in that it comprises:

a plurality of nozzles for jetting therefrom ink jets;

exciting means provided for each of said nozzles for causing an ink jet from the nozzle to disintegrate into drops of ink in response to an exciting clock signal;

charging means provided for each of said nozzles for selectively charging such drops of ink from the nozzle in accordance with a controlling signal;

said nozzles being arranged such that drops of ink formed from ink jets therefrom may impinge in an overlapping relationship at a location on a record medium

supported on a rotary drum when all of said charging means for said nozzles are controlled by a same controlling signal; and

a registration adjusting system including dot clock generating means for producing a first picture element recording clock signal from a rotary drum position signal representative of a rotational position of said rotary drum, said registration adjusting system further including registration adjusting means provided for each of said nozzles, each of the registration adjusting means including frequency multiplying means for multiplying a frequency of the first picture element recording clock signal to produce a first registration adjusting clock signal, start position delaying means for producing, from the first registration adjusting clock signal, a second registration adjusting clock signal which is delayed by a time corresponding to external variable instruction data from an original position pulse signal representative of an original position of said rotary drum, synchronizing means for producing, from the first picture element recording clock signal, a second picture element recording clock signal synchronized with the second registration adjusting clock signal and the exciting clock signal, a line buffer for storing picture image data therein and for being controlled in accordance with the second picture element recording clock signal to recall the stored data therefrom, controlling signal generating means for generating, from

the second picture element recording clock signal, a loading signal delayed by a predetermined time, pulse width modulating means for receiving picture element data read out from said line buffer in response to the loading signal to output a pulse width modulating signal having a pulse width corresponding to the thus received picture image data, and high voltage switching means for voltage controlling the pulse width modulating signal to produce a controlling signal for the corresponding charging means.

It is an object of the present invention to provide an ink jet recording apparatus of the continuous jet type wherein an optimum phase between disintegration of a jet of ink and a recording pulse signal is automatically adjusted to assure high quality printing.

According to one aspect of the present invention, there is provided an ink jet recording apparatus of the continuous jet type comprising:

jet forming means including a nozzle for pressurizing ink to form a jet of ink;

exciting means (FD, DG, MP2, VD) for exciting a vibrating element mounted on said nozzle in response to an applied periodic excitation signal at a frequency at or around a spontaneous disintegrating frequency of the ink jet to cause an ink jet from said jet forming means to be disintegrated into ink drops in synchronism with such excitation;

charging means for causing selected said ink drops to be electrically charged and means for selectively applying voltage pulse signals to said charging means, for electrically charging said selected ink drops;

deflecting means for selectively producing a deflecting electric field and deflecting a charged ink drop when a deflecting electric field is produced but allowing a charged ink drop to advance straightforwardly when no deflecting electric field is produced;

an electrically isolated conductive drop catcher operable, in an optimum-phase-determining mode of the apparatus to catch said ink drops,

a current detector and integrator (SW2, SW3, SW4, C, OP) connected to said electrically isolated conductive drop catcher for measuring the electrical current (I_j) carried by the charged ink drops reaching the drop catcher, and herein referred to as the jet current, and for integrating said current over a predetermined period to afford a value indicative of the charge per ink drop over that period; and

computer means controlling said means for selectively applying said voltage pulse signals or controlling said exciting means for controlling the phase relationship between said voltage pulse signals and said excitation signals, said computer means including means for storing a plurality of said values, said computer means being operable, in said optimum-phase-determining mode, to

establish, over each of a plurality of such periods, a different phase relationship between the voltage pulse signals and the excitation signals, to store the respective said values and corresponding phase relationships and to select an optimum phase relationship in accordance with the ranking of the stored values by magnitude, said computer means being arranged to maintain the optimum phase relationship thus selected during a subsequent period of operation of the apparatus in a normal operating mode.

With the ink jet recording apparatus of the invention, ink drops can be controlled individually with certainty. Accordingly, drop noises which may otherwise be caused principally at a highlight portion of a recorded picture image by incompletely charged ink drops can be eliminated.

According to another aspect of the invention, there is provided a method of operating an ink jet recording apparatus of the continuous jet type comprising:

jet forming means including a nozzle for pressurizing ink to form a jet of ink;

exciting means (FD, DG, MP2, VD) for exciting a vibrating element mounted on said nozzle in response to an applied periodic excitation signal at a frequency at or around a spontaneous disintegrating frequency of the ink jet to cause an ink jet from said jet forming means to be

disintegrated into ink drops in synchronism with such excitation;

charging means for causing selected said ink drops to be electrically charged and means for selectively applying voltage pulse signals to said charging means, for electrically charging said selected ink drops;

deflecting means for selectively producing a deflecting electric field and deflecting a charged ink drop when a deflecting electric field is produced but allowing a charged ink drop to advance straightforwardly when no deflecting electric field is produced;

the method including determining the optimum phase relationship between said voltage pulse signals and said excitation signal by applying a said voltage pulse signal for each said ink drop produced over a testing period whereby each said ink drop produced over the testing period is an electrically charged ink drop, catching said charged ink drops by an electrically isolated conductive drop catcher,

integrating, over said testing period, the electrical current (I_j) carried by the charged ink drops reaching the drop catcher, and herein referred to as the jet current, to afford a value indicative of the charge per ink drop over that period;

varying the phase relationship between said voltage pulse signals and said excitation signals, so that said phase relationship is different over a series of such test

periods and determining the optimum phase relationship between said voltage pulse signals and said excitation signals by determining the range of such phases for which said value is relatively high and selecting, as the optimum phase, a phase relation within that range, and thereafter maintaining the optimum phase relationship so determined during a period of operation of the apparatus.

Embodiments of the invention are described below by way of example with reference to the accompanying drawings, in which:-

FIGURE 1 is a block diagram of an ink jet recording apparatus embodying the present invention;

FIGURE 2 is a block diagram of a synchronizing signal generating circuit for generating a synchronizing signal for the synchronous control of a current detector of the ink jet recording apparatus of Figure 1;

FIGURE 3 is a time chart illustrating operation of the synchronizing signal generating circuit of Figure 2;

FIGURE 4 is a time chart illustrating a relationship among production of ink drops, an exciting signal and a controlling signal (probe pulse signal) in the ink jet recording apparatus of Figure 2;

FIGURE 5 is a time chart illustrating a phase relationship between a probe pulse signal and an exciting signal in the ink jet recording apparatus of Figure 2;

FIGURE 6 is a graph showing a result of measurement of a relationship between an exciting signal and a jet current in the ink jet recording apparatus of Figure 2,

FIGURE 7 is a block diagram similar to Figure 1 but showing a modification of the apparatus of Figure 1, and

FIGURE 8 is a block diagram showing a conventional continuous jet type ink jet recording apparatus.

Referring to Figure 1 there is shown a continuous jet type ink jet recording apparatus to which the present invention is applied. The ink jet recording apparatus includes a nozzle 1 having a circular orifice (not shown) of a very small diameter, an ink electrode 2 for holding the potential of ink in the nozzle 1 at a ground level, a vibrating element 3 in the form of a piezoelectric vibrating element mounted on the nozzle 1, a controlling electrode 4 having a circular opening or a slit-like opening coaxial with the nozzle 1 for receiving

a controlling signal to control charging of a jet of ink in response to picture image data, a grounding electrode 5 disposed in front of the controlling electrode 4 and grounded itself, a knife edge 6 mounted on the grounding electrode 5, a deflecting power source E1, a deflecting electrode 7 connected to the deflecting power source E1 for cooperating with the grounding electrode 5 to produce therebetween an intense electric field perpendicular to an ink jet flying axis to deflect a charged ink drop to —

the grounding electrode 5 side, a switch SW1 for alternatively connecting the deflecting electrode 7 to the deflecting power source E1 or the ground, a reference oscillator CG for generating a reference clock signal CLK, a frequency divider FD for frequency dividing such reference clock signal CLK into one N-th (N is a positive integer) to produce an exciting clock signal PCLK, a delay pulse generator DG for successively delaying the exciting clock signal PCLK to N stages in response to the reference clock signal CLK to produce a train of pulses θ_0 , θ_1 , θ_2 , ... and θ_{N-1} , a multiplexer (2) for selecting one of the delayed pulses θ_0 , θ_1 , θ_2 , ... and θ_{N-1} , a vibrating element driver VD for driving the vibrator 3 in response to a pulse selected by the multiplexer (2) MP2, a pulse width modulator PWM for converting picture image data into a pulse width corresponding to a density gradation, a probe pulse generator PG for producing, in synchronism with a rising or falling edge of the exciting clock signal PCLK, a probe pulse having a sufficiently small pulse width comparing with a period of the exciting clock signal PCLK, a synchronizing circuit SC for synchronizing a rising or falling edge of an output of the pulse width modulator PWM with a rising or falling edge of the

exciting clock signal PCLK, another multiplexer (1) MP1 for selecting one of a probe pulse from the probe pulse generator PG and an output of the synchronizing circuit SC, a high voltage switch HVS for voltage amplifying an output of the multiplexer (1) MP1 to produce a controlling signal to be applied to the controlling electrode 4, a conductive drop catcher 8 disposed at a location (hereinafter referred to as home position) forwardly of the grounding electrode 5 and deflecting electrode 7 and serving also as a detecting electrode, a shield line 9 having an end connected to the conductive drop catcher 8, a current detector or current to voltage converter composed of three switches SW2, SW3 and SW4, an integrating capacitor C and an integrator OP, and an analog to digital (A/D) converter ADC for converting an output of the current detector from an analog signal into a digital signal.

The delay pulse generator DG is constructed, for example, from a serial-in parallel-out type N-bit shift register.

The probe pulse generator PG is constructed, for example, from a monostable multivibrator which is triggered by an edge of an exciting clock signal PCLK.

The integrating capacitor C suitably has a

capacitance of 1 to 10 nF or so and preferably has a high insulation resistance such as a polystyrol or polypropylene capacitor.

The integrator OP is constructed from an operational amplifier of an FET (field effect transistor) input with which a leak current (less than 1 nA) can be ignored comparing with a jet current I_j , and the input thereof is connected to a virtual grounding point thereof.

Also the switches SW2, SW3 and SW4 are each constructed from an FET with which a leak current can be ignored comparing with the jet current I_j .

Referring now to FIG. 2, there is shown a synchronizing signal generating circuit for generating a synchronizing signal to cause the switches SW2, SW3 and SW4 to operate in synchronism with commercial power supply of, for example, ac 100 V. The synchronizing signal generating circuit is composed of a transformer T, a resistor R, a pair of diodes D1 and D2, a preset counter PSC, and a pair of flip-flops FF1 and FF2.

The preset counter PSC can be set to a variable preset value by way of a route not shown, and the integration time of the integrator OP can be arbitrarily set to a value an integral number of times the period of

the commercial power supply of ac 100 V by changing such preset value of the preset counter PSC. In the present continuous jet type ink jet recording apparatus, the integration time is set to three times the period of the commercial power supply of ac 100 V as seen from FIG. 3.

A reset signal RESET, an integration starting signal HOLD and an integration ending signal HOLD are produced from the synchronizing signal generating circuit. Such reset signal RESET, integration starting signal HOLD and integration ending signal HOLD are fixed to one period of the commercial power supply of ac 100 V, and when they present a high ("H") level, the switches SW4, SW3 and SW2 are closed, but when they present a low ("L") level, the switches SW4, SW3 and SW2 are open, respectively.

In operation, when power is made available to the continuous jet type ink jet recording apparatus, an operating voltage is supplied to the circuit system shown in FIGS. 1 and 2, whereupon the circuit system starts its operation. First, a phase adjusting operation is performed. It is to be noted that such phase adjusting operation is normally performed when a carriage (not shown) on which the nozzle 1 is carried is

positioned at its home position and immediately before a recording operation is started. Where the continuous jet type ink jet recording apparatus is constructed as a color ink jet printer, it includes four or three such nozzles 1 for four colors (C (cyan), M (magenta), Y (yellow) and BK (black)) or three colors (C, M and Y) and a phase adjusting operation is performed parallelly for the four or three nozzles 1.

First, ink is pressurized by an ink pump (not shown) and introduced into the nozzle 1 by way of an ink tube (not shown). Consequently, an ink jet is jetted from the nozzle 1, and the nozzle 1 is thereafter kept in such steady condition wherein an ink jet is being jetted. Meanwhile, an MPU (not shown) changes over the switch SW1 to the grounding side to change the level of the deflecting electrode 7 to a ground level. Consequently, the deflecting electric field between the grounding electrode 5 and deflecting electrode 7 disappears. Consequently, also a charged ink drop can pass by the knife edge 6. Further, the MPU controls the multiplexer (1) MP1 to select an output of the probe pulse generator PG. Furthermore, the carriage on which the nozzle 1 is carried is set to the home position by a carriage motor (not shown).

Meanwhile, the reference oscillator CG develops a reference clock signal CLK, and such reference clock signal CLK is divided in frequency into one N-th ($1/N$) by the frequency divider FD thereby to form an exciting pulse signal PCLK. Such exciting pulse signal PCLK has an exciting frequency PCLK (in the following description, a signal and a frequency of such signal are denoted by a same reference character) given by CLK/N . For example, when the reference clock frequency CLK is $CLK = 16 \text{ MHz}$ and the dividing ratio N of the frequency divider FD is $N = 16$, the exciting signal frequency PCLK is $PCLK = 1 \text{ MHz}$ ($= 16/16$). The exciting pulse signal PCLK outputted from the frequency divider FD is inputted to the delay pulse generator DG, probe pulse generator PG and synchronizing circuit SC.

The delay pulse generator DG receives the exciting clock signal PCLK as data and the reference clock signal CLK as a shift clock signal and outputs a train of N pulses $\theta_0, \theta_1, \theta_2, \dots$ and θ_{N-1} having a same period as the exciting clock signal PCLK but having phases delayed successively by $2\pi/N$ from the exciting clock signal PCLK. One of the N pulses $\theta_0, \theta_1, \theta_2, \dots$ and θ_{N-1} is selected by the MPU by way of the multiplexer (2) MP2 and transmitted to the vibrating

element driver VD. The vibrating element driver VD excites the vibrating element 3 in response to an output signal of the multiplexer (2) MP2. Consequently, a jet of ink jetted from the nozzle 1 is disintegrated into ink drops in synchronism with such excitation of the vibrating element 3.

The probe pulse generator PG generates, in a synchronized relationship with a rising or falling edge (which is same as that upon recording) of the exciting clock signal PCLK, such a probe pulse having a pulse width sufficiently short comparing with a period of the exciting clock signal PCLK as seen in FIG. 3. For example, when the exciting clock signal PCLK has a period of 1 μ sec (oscillated at 1 MHz), the pulse width of the probe pulse from the probe pulse generator PG is 0.1 to 0.3 μ sec.

The probe pulse outputted from the probe pulse generator PG is inputted by way of the multiplexer (1) MP1 to the high voltage switch HVS, at which it is voltage amplified to form a controlling signal, and such controlling signal is applied to the controlling electrode 4. Accordingly, a drop of ink disintegrated in synchronism with excitation of the vibrating element 3 is charged in response to such probe pulse. When the

continuous jet type ink jet recording apparatus operates in such a manner as illustrated in FIG. 3. An ink drop is always charged, but a charging voltage is removed only while a probe pulse is applied as a controlling signal to the controlling electrode 4 (for example, for 0.1 to 0.3 μ sec).

Since the deflecting electric field is not present, even a charged ink is not deflected and passes by the knife edge 6 so that it is caught by the conductive drop catcher 8 located at the home position and electrically isolated from the other electric components.

Charge of charged ink drops caught by the conductive drop catcher 8 is inputted as a jet current I_j to the current detector, which is composed of the switches SW2, SW3 and SW4, integrating capacitor C and integrator OP, by way of the shield line 9, so that it is integrated for a fixed period of time by the integrator OP. The thus integrated charge appears as a voltage across the integrating capacitor C.

The switches SW2, SW3 and SW4 operate in synchronism with the commercial power supply of ac 100 V in order to remove noises included in the commercial power supply of ac 100 V and any other noises from an

input current to the integrator OP so that only the jet current I_j may be integrated by the integrator OP and transmitted to the A/D converter ADC.

More particularly, in the synchronizing signal generating circuit shown in FIG. 2, the commercial power supply of ac 100 V is stepped down by the transformer T and clamped at 0 V and 5 V by the diodes D1 and D2, and a thus clamped signal is supplied to a Schmitt gate SG, at which a clock signal CK of a TTL (transistor-transistor logic) level synchronized with the commercial power supply of ac 100 V is produced. From the clock signal CK, such an integration ending signal HOLD, an integration starting signal $\overline{\text{HOLD}}$ and a reset signal RESET as shown in FIG. 3 are produced by the preset counter PSC and flip-flops FF1 and FF2.

When the reset signal RESET changes from a low level to a high level, the switch SW4 is closed to short-circuit the integrating capacitor C. Consequently, the output of the integrator OP is reset to 0 V.

When the reset signal RESET changes from a high level to a low level after one period of the commercial power supply of ac 100 V, the switch SW4 is opened. Since the integration ending signal HOLD is at a low

level (the switch SW2 is open) and the integration starting signal HOLD is at a high level (the switch SW3 is closed) then, the jet current I_j will thereafter flow into a virtual grounded point of the operational amplifier constituting the integrator OP, thereby starting an integrating operation of the integrator OP.

When an interval of time equal to the predetermined integral number of times (three times in the case shown in FIG. 3) the period of the commercial power supply of ac 100 V elapses after starting of such integrating operation, the integration ending signal HOLD changes from a low level to a high level so that the switch SW2 is closed while the integration starting signal HOLD changes from a high level to a low level so that the switch SW3 is opened. Consequently, the jet current I_j is interrupted, and the jet current I_j which has been integrated by the integrating capacitor C till then is thereafter held as a voltage output of the integrator OP. Now, since an ink jet is charged in accordance with a controlling signal (probe pulse) applied to the controlling electrode so that it may have a negative charge, the jet current I_j flows in the direction indicated by an arrow mark in FIG. 1 into the integrating capacitor C, and the output of the

integrator OP presents a high voltage.

By the way, it is almost impossible with an actual machine to perfectly shield a route between the conductive drop catcher 8 to the integrator OP from noises. Therefore, during an integrating operation, noises included in the commercial power supply of ac 100 V and high frequency noises produced from peripheral electronic appliances are overlapped in an output of the integrator OP. Among such noises, high frequency noises are averaged and do not matter because the integrating time is longer than one period of the commercial power supply of ac 100 V and sufficiently long. Meanwhile, noises of the commercial power supply of ac 100 V are averaged during an integrating period and accordingly are removed automatically since the integrating time is set to an integral number of times the period of the commercial power supply of ac 100 V.

After an integrating operation is completed, the integration starting signal HOLD changes from a high level to a low level so that the switch SW3 is opened, and consequently, simultaneously when the jet current I_j is interrupted, also noises coming to the integrator OP from the input side are interrupted. Accordingly, if only the integrator OP is interrupted sufficiently, then

noises which may matter are only those which are generated in the inside of the integrator OP, and consequently, the jet current I_j can be measured with a very high degree of accuracy. In this manner, a current detector having a very high performance can be constructed using simple and inexpensive devices.

The jet current I_j converted into a voltage by the integrator OP is then converted into digital data by the A/D converter ADC and outputted into a data bus (not shown) to the MPU. It is to be noted that, though not shown, the integration ending signal HOLD is supplied to the MPU, and the MPU instructs the A/D converter ADC to perform an analog to digital converting operation in synchronism with the integration ending signal HOLD.

Such measurement of a jet current I_j described above is performed for each of the pulses θ_0 , θ_1 , θ_2 , ..., and θ_{N-1} , which are successively displaced in phase by $2\pi n/N$ ($n = 0, 1, 2, \dots, N-1$) from the exciting clock signal PCLK, by successively changing over the multiplexer (2) MP2 so that the vibrator 3 may be successively driven in response to the pulses θ_0 , θ_1 , θ_2 , ..., and θ_{N-1} to excite the nozzle 1 as seen from FIG. 5.

A value of the jet current I_j measured for each

of the phases is converted from an analog value to a digital value by the A/D converter ADC and stored into a RAM (random access memory) (not shown) of the MPU.

FIG. 6 shows a result of plotting of values of the jet current I_j measured for the individual phases using test picture image data. Presence or absence of an incompletely charged ink drop is determined by observation on a stroboscope using a microscope, and a small mark ○ represents absence of an incompletely charged ink drop while another small mark ● represents presence of an incompletely charged ink drop. The fact that the result of measurement indicates such a tendency as shown in FIG. 6 can be understood because such forbidden region as mentioned hereinabove appears in synchronism with an exciting signal and the jet current I_j is low when incompletely charged ink drops are present, but is high when no incompletely charged ink drop is present (refer to U.S. Patent No. 4,839,665 and C. H. Hertz and B. A. Samuelsson, J. Imag. Tech., 15, 141, 1989).

The MPU determines, in accordance with algorithm in the form of software, an optimum phase (θ_{12} or θ_{13} in FIG. 6) with which charged ink drops and non-charged ink drops are separated completely from each other with

respect to a rising or falling edge of a controlling signal against a variation in phase and no incompletely charged ink drop is produced. Then, the MPU controls the multiplexer (2) MP2 to select the phase θ_{12} or θ_{13} . In the case of $N = 16$, the jet current I_j is successively measured while the phase θ is varied in the direction indicated by an arrow mark in FIG. 6, and preferably the optimum phase is set to a phase prior by three phase distances or so to another phase at which the jet current I_j presents a maximum value, that is, to a phase prior by amount $3 \cdot 2\pi/16 = 3\pi/8$ (67.5 degrees) to such phase. It is to be noted that an optimum phase set once in this manner will not be changed during recording on one page of a record medium. Consequently, recording on one page of a record medium is performed in a same phase.

After completion of such phase adjustment, the MPU changes over the switch SW1 to the deflecting power source E1 side to apply a deflecting voltage to the deflecting electrode 7 in order to perform recording on a record medium. Consequently, a deflecting electric field is produced so that a charged ink drop passing between the grounding electrode 5 and the deflecting electrode 7 will be deflected to the grounding electrode

5 side and cut by the knife edge 6. Further, the MPU changes over the multiplexer (1) MP1 so as to select an output of the synchronizing circuit SC. Consequently, a pulse width modulating signal for picture element data will be inputted to the high voltage switch HVS.

On the other hand, upon recording, picture element data, which are synchronized with a picture element recording instruction signal DCLK produced from an output of a shaft encoder (not shown) directly coupled to a rotary drum (not shown), are transmitted from a line buffer (not shown; a line memory in which picture image data for one full rotation of the rotary drum are stored) to the pulse width modulator PWM, at which each picture image data are converted into a pulse width corresponding to a gradation in density thereof. An output of the pulse width modulator PWM is transmitted to the synchronizing circuit SC.

The synchronizing circuit SC synchronizes a rising or falling edge of the output of the pulse width modulator PWM with a rising or falling edge of an exciting clock signal PCLK.

An output of the synchronizing circuit SC is inputted by way of the multiplexer (1) MP1 to the high voltage switch HVS, at which it is voltage amplified to

a potential necessary for charging of an ink jet to produce a controlling signal. Such controlling signal is applied to the controlling electrode 4. A jet of ink is thus induction charged in response to such controlling signal, and a drop of the thus charged ink is deflected to the grounding electrode 5 side by an action of the deflecting electric field and cut by the knife edge 6 while only a non-charged ink drop is allowed to advance straightforwardly so that it passes by the knife edge 6 and forms a dot on a record medium wrapped on the rotary drum. Consequently, recording on one page of the record medium can be performed while picture image data (output of the pulse width modulator PWM) are synchronized with the exciting signal PCLK and besides held in an optimum phase relationship with disintegration of an ink jet.

It is to be noted that, when an ink jet is interrupted once, particularly when such interruption of an ink jet continues for a long time, an optimum phase condition is varied delicately by a variation of physical property values of ink by variation of the temperature or by a variation of jetting conditions, and accordingly, it is desirable to perform a phase adjusting operation immediately before starting of each

recording operation.

Further, in case the integration time is set to three times the period of the commercial power supply of ac 100 V as in the continuous jet type ink jet recording apparatus described above, a resetting section and a holding section must be added, and consequently, a total of 5 periods of the commercial power supply of ac 100 V, that is, in the case of a 50 Hz area, a total of 0.1 sec. is required for measurement of a jet current I_j of one phase. Accordingly, even if measurement is performed for a total of 16 phases ($N = 16$), a total time required for phase adjustment is only 1.6 seconds (the processing time of the MPU can be ignored because it operates at a very high speed). Even in the case of a color ink jet printer, since measurement is performed parallelly for four colors (C, M, Y and BK) or three colors (C, M and Y), a time required for phase adjustment is equal to that of a continuous jet type ink jet recording apparatus for a single color.

Referring now to FIG. 7, there is shown a modification to the continuous jet type ink jet recording apparatus of FIG. 1. The modified continuous jet type ink jet recording apparatus is constructed such that, while the continuous jet type ink jet recording

apparatus of FIG. 1 is constructed such that, in order to determine an optimum phase between disintegration of an ink jet and a recording pulse, an exciting clock signal PCLK is delayed to find out an optimum phase, a recording pulse is delayed to find out an optimum phase. In particular, the present continuous jet type ink jet recording apparatus is modified such that an exciting clock signal PCLK outputted from the frequency divider FD is inputted directly to the vibrating element driver VD, and an output of the multiplexer (2) MP2 is inputted to the probe pulse generator PG and the synchronizing circuit SC.

Also with the present continuous jet type ink jet recording apparatus constructed in this manner, a phase between an exciting clock signal and a recording pulse is automatically adjusted to an optimum one similarly as with the continuous jet type ink jet recording apparatus of FIG. 1 while it is only different that a phase of a controlling signal (probe pulse) is successively displaced by $2\pi/N$ to different stages when measurement of the jet current I_j is proceeded.

It is to be noted that several examinations have been conducted using a continuous jet type ink jet

recording apparatus manufactured in accordance with the present invention, and it has been confirmed from the examinations that a jet current I_j can be measured at a sufficiently high S/N ratio so far as the integrating time ranges from 1 to 10 periods of the commercial power supply of ac 100V.



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CLAIMS

1. An ink jet recording apparatus of the continuous jet type comprising:

jet forming means (1) including a nozzle (1) for pressurizing ink to form a jet of ink;

exciting means (FD, DG, MP2, VD) for exciting a vibrating element (3) mounted on said nozzle (1) in response to an applied periodic excitation signal at a frequency at or around a spontaneous disintegrating frequency of the ink jet to cause an ink jet from said jet forming means to be disintegrated into ink drops in synchronism with such excitation;

charging means for causing selected said ink drops to be electrically charged and means for selectively applying voltage pulse signals to said charging means, for electrically charging said selected ink drops;

deflecting means (5, 7) for selectively producing a deflecting electric field and deflecting a charged ink drop when a deflecting electric field is produced but allowing a charged ink drop to advance straightforwardly when no deflecting electric field is produced;

an electrically isolated conductive drop catcher (8) operable, in an optimum-phase-determining mode of the apparatus to catch said ink drops,



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a current detector and integrator (SW2, SW3, SW4, C, OP) connected to said electrically isolated conductive drop catcher (8) for measuring the electrical current (I_j) carried by the charged ink drops reaching the drop catcher, and herein referred to as the jet current, and for integrating said current over a predetermined period to afford a value indicative of the charge per ink drop over that period; and

computer means controlling said means for selectively applying said voltage pulse signals or controlling said exciting means for controlling the phase relationship between said voltage pulse signals and said excitation signals, said computer means including means for storing a plurality of said values, said computer means being operable, in said optimum-phase-determining mode, to establish, over each of a plurality of such periods, a different phase relationship between the voltage pulse signals and the excitation signals, to store the respective said values and corresponding phase relationships and to select an optimum phase relationship in accordance with the ranking of the stored values by magnitude, said computer means being arranged to maintain the optimum phase relationship thus selected during a subsequent period of operation of the apparatus in a normal operating mode.

2. An ink jet recording apparatus according to claim 1, which is adapted to be connected with a commercial a.c.



supply and wherein said current detector and integrator is arranged to integrate jet current over an integral number of periods of said a.c. supply.

3. An ink jet recording apparatus according to claim 1 or claim 2 including a clock providing periodic clock pulse signals, a frequency divider receiving said clock signals and producing pulse output signals at a frequency which is substantially greater than the frequency of said periodic excitation signal, said excitation signals being derived from, and corresponding in phase and frequency with said pulse output signals from said divider, and wherein delay pulse generating means is provided which receives said clock pulse signals and said pulse output signals from said divider and produces output pulses of the same duration and frequency as said pulse output signals from the divider but which are displaced in phase relative to the latter by an amount determined by said computer means, and wherein the pulses from the delay pulse generating means provide said voltage pulse signals to said charging means and the output signals from said frequency divider provide said excitation signals to said exciting means.

4. An ink jet recording apparatus according to claim 1 or claim 2 including a clock providing periodic clock pulse signals, a frequency divider receiving said clock signals and producing pulse output signals at a frequency



which is substantially greater than the frequency of said periodic excitation signal, said excitation signals being derived from, and corresponding in phase and frequency with said pulse output signals from said divider, and wherein delay pulse generating means is provided which receives said clock pulse signals and said pulse output signals from said divider and produces output pulses of the same duration and frequency as said pulse output signals from the divider but which are displaced in phase relative to the latter by an amount determined by said computer means, and wherein the pulses from the delay pulse generating means provide said excitation signals to said exciting means and the output signals from said frequency divider provide said voltage pulse signals to said charging means.

5. An ink jet recording apparatus as set forth in claim 1 or claim 2, characterised in that said current detector and integrator (SW2, SW3, SW4, C, OP) includes an integrating circuit (OP), and a plurality of switches (SW2, SW3, SW4) for controlling starting and ending of an integrating operation and resetting of said integrator (OP).

6. An ink jet recording apparatus as set forth in claim 5, when dependent on claim 2, characterised in that said switches (SW2, SW3, SW4) operate in synchronism with said commercial a.c. power supply.



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7. A method of operating an ink jet recording apparatus of the continuous jet type comprising:

jet forming means (1) including a nozzle (1) for pressurizing ink to form a jet of ink;

exciting means (FD, DG, MP2, VD) for exciting a vibrating element (3) mounted on said nozzle (1) in response to an applied periodic excitation signal at a frequency at or around a spontaneous disintegrating frequency of the ink jet to cause an ink jet from said jet forming means to be disintegrated into ink drops in synchronism with such excitation;

charging means for causing selected said ink drops to be electrically charged and means for selectively applying voltage pulse signals to said charging means, for electrically charging said selected ink drops;

deflecting means (5, 7) for selectively producing a deflecting electric field and deflecting a charged ink drop when a deflecting electric field is produced but allowing a charged ink drop to advance straightforwardly when no deflecting electric field is produced;

the method including determining the optimum phase relationship between said voltage pulse signals and said excitation signal by applying a said voltage pulse signal for each said ink drop produced over a testing period whereby each said ink drop produced over the testing period is an electrically charged ink drop, catching said charged



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ink drops by an electrically isolated conductive drop catcher,

integrating, over said testing period, the electrical current (I_j) carried by the charged ink drops reaching the drop catcher, and herein referred to as the jet current, to afford a value indicative of the charge per ink drop over that period;

varying the phase relationship between said voltage pulse signals and said excitation signals, so that said phase relationship is different over a series of such test periods and determining the optimum phase relationship between said voltage pulse signals and said excitation signals by determining the range of such phases for which said value is relatively high and selecting, as the optimum phase, a phase relation within that range, and thereafter maintaining the optimum phase relationship so determined during a period of operation of the apparatus.

8. An ink jet recording apparatus substantially as hereinbefore described with reference to, and as shown in, Figures 1 to 6 of the accompanying drawings.