United States Patent [19]

Helinski et al.

[11] **3,928,855**

[45] **Dec. 23, 1975**

[54] **METHOD AND APPARATUS FOR CONTROLLING SATELLITES IN AN INK JET PRINTING SYSTEM**

[75] Inventors: **Edward F. Helinski,** Johnson City; **Ho C. Lee,** Endicott; **Jack L. Zable,** Vestal, all of N.Y.

[73] Assignee: **International Business Machines Corporation,** Armonk, N.Y.

[22] Filed: **Dec. 18, 1974**

[21] Appl. No.: **533,913**

[52] **U.S. Cl.** **346/1;** 346/75

[51] **Int. Cl.**^{2} **G01D 15/18**

[58] **Field of Search** .... 346/75, 140, 1; 197/1 R

[56] **References Cited**

UNITED STATES PATENTS

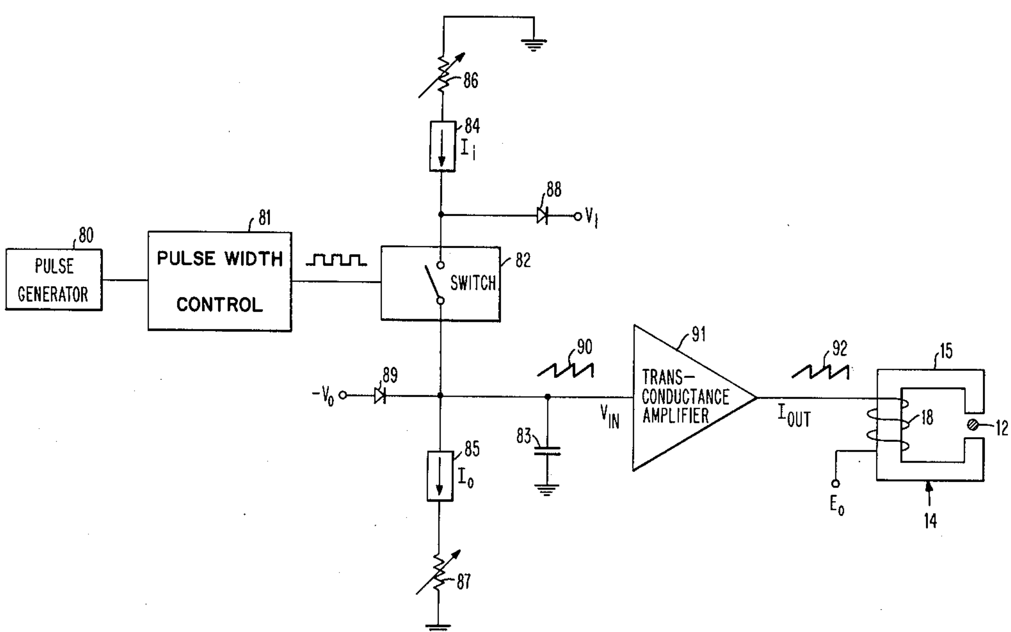
3,334,351	8/1967	Stauffer	346/75
3,596,275	7/1971	Sweet	346/75 X
3,683,396	8/1972	Keur et al.	346/75 X

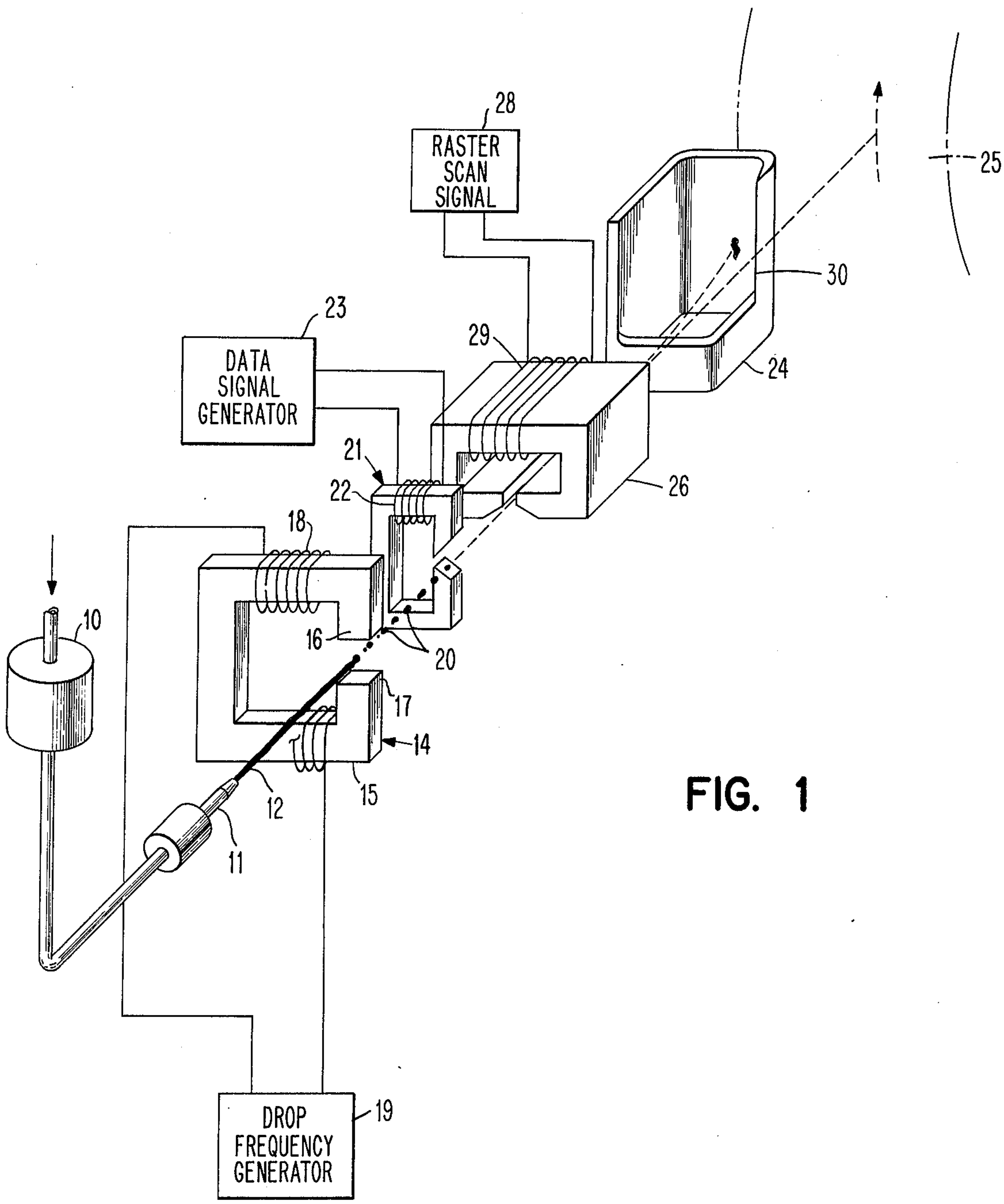
Primary Examiner—Joseph W. Hartary
Attorney, Agent, or Firm—John S. Gasper

[57] **ABSTRACT**

A continuous jet stream of a ferrofluid ink is broken into individual drops by an asymmetrical perturbation force applied to the stream. The ink, as it exits from an orifice under pressure, is excited by an electromagnetic transducer energized with an asymmetrical excitation signal having a fundamental and higher harmonics. An asymmetrical excitation signal, such as a sawtooth, having a substantial second and/or third harmonics content which produce an excitation signal with different rise and fall times can form a stream of drops free of satellites. Asymmetry of magnetic field forces can be produced with single stage or multistage transducers located at spaced positions along the stream. Asymmetry can also be produced using an electromagnetic transducer having a non-uniform gap.

20 Claims, 22 Drawing Figures





28
RASTER SCAN SIGNAL
25
30
23
DATA SIGNAL GENERATOR
29
24
21
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18
10
16
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17
14
12
15
11
DROP FREQUENCY GENERATOR
19

FIG. 1

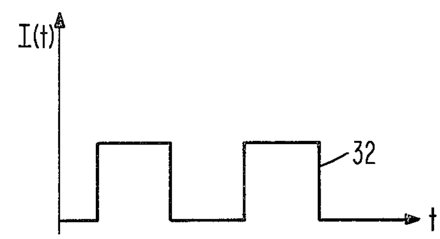

FIG. 2A

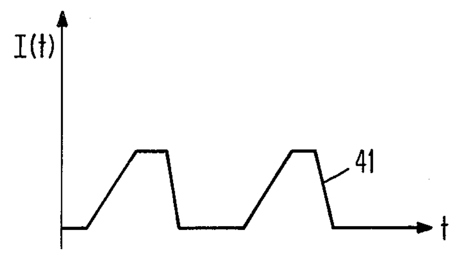

FIG. 3A

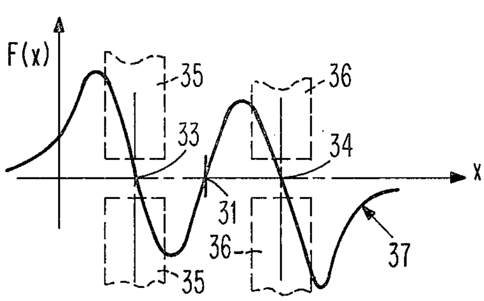

FIG. 2B

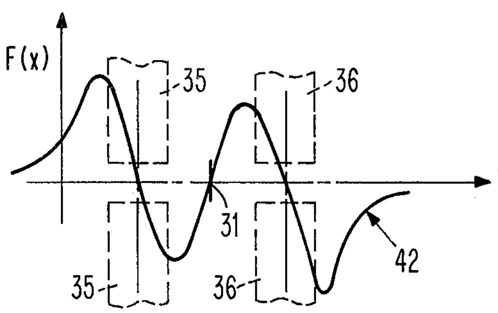

FIG. 3B

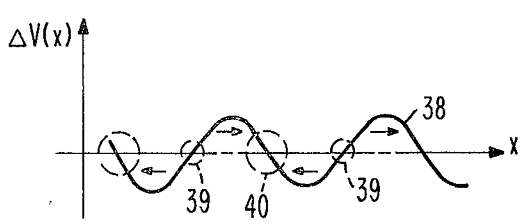

FIG. 2C

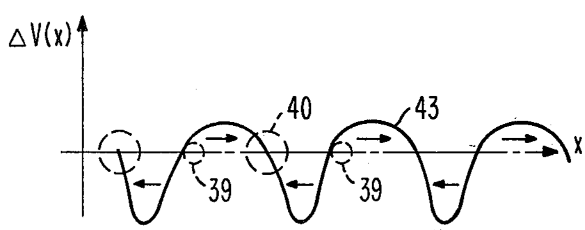

FIG. 3C

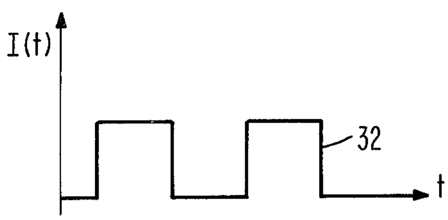

FIG. 4A

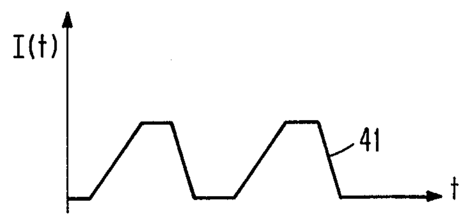

FIG. 5A

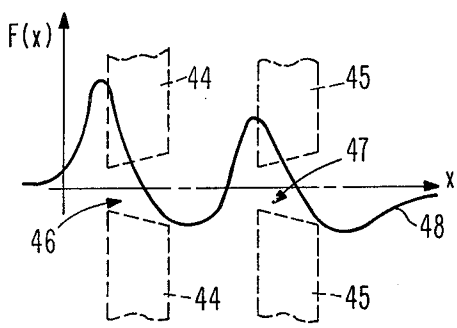

FIG. 4B

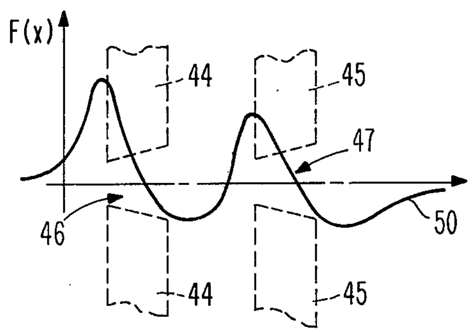

FIG. 5B

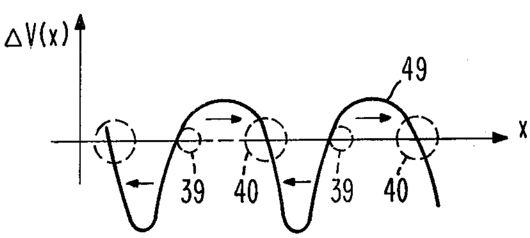

FIG. 4C

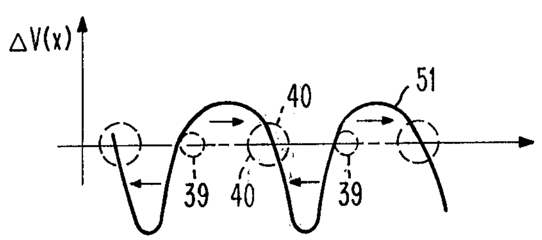

FIG. 5C

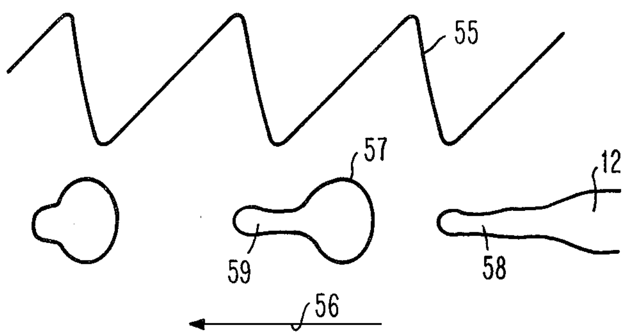

FIG. 6

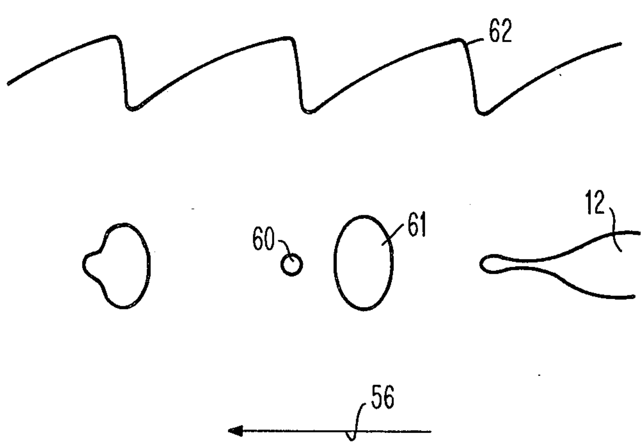

FIG. 7

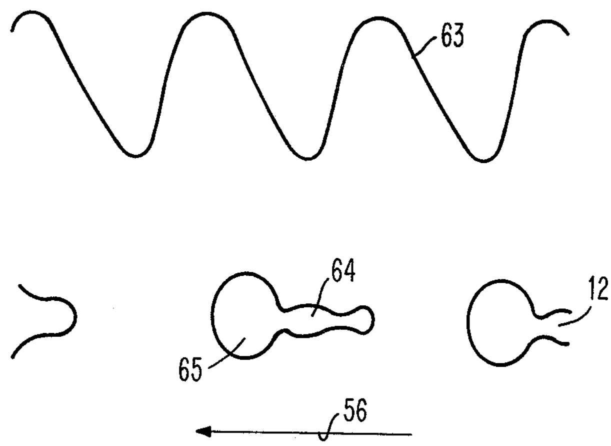

FIG. 8

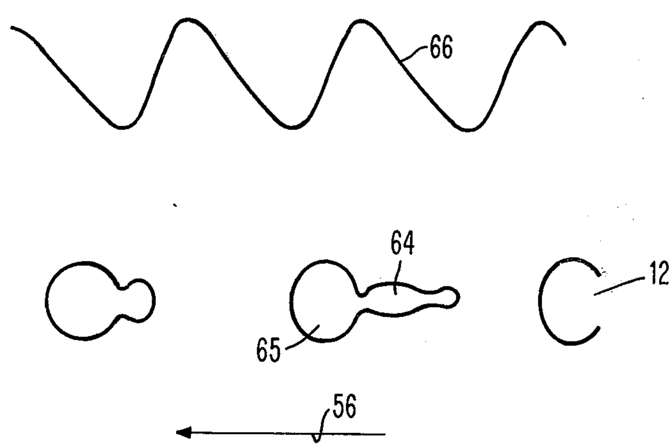

FIG. 9

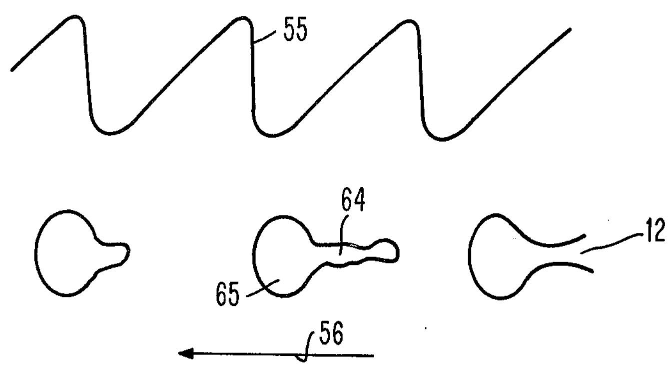

FIG. 10

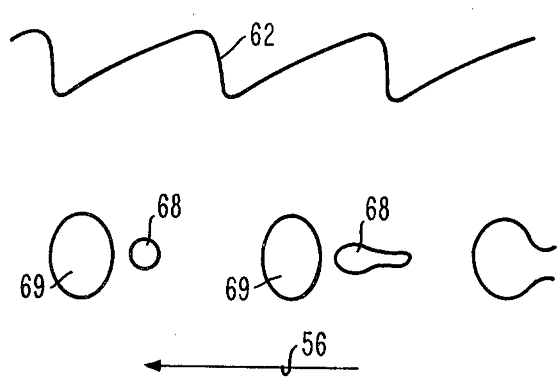

FIG. 11

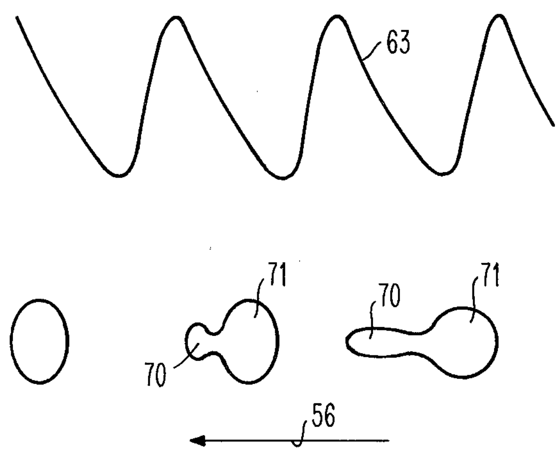

FIG. 12

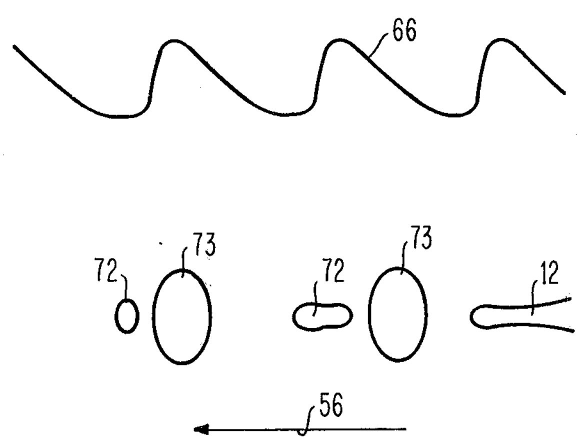

FIG. 13

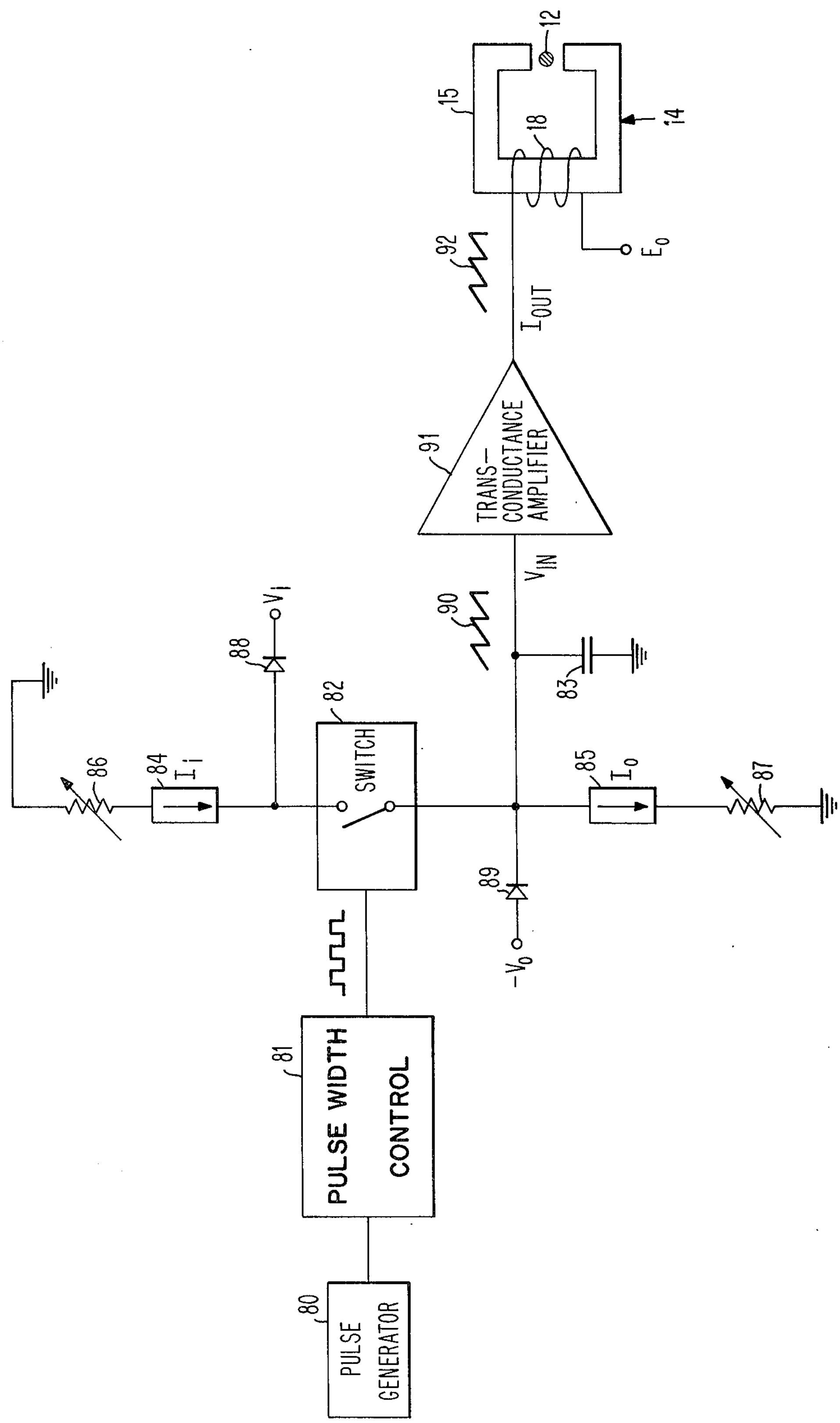
PULSE GENERATOR
80
PULSE WIDTH CONTROL
81
SWITCH
82
83
84
I_i
85
I_o
86
87
88
V_i
89
$-V_0$
90
V_{IN}
TRANS-CONDUCTANCE AMPLIFIER
91
92
I_{OUT}
E_0
15
12
18
14

FIG. 14

METHOD AND APPARATUS FOR CONTROLLING SATELLITES IN AN INK JET PRINTING SYSTEM

CROSS-REFERENCES TO RELATED APPLICATIONS

Application of Joseph P. Pawletko and Bruce A. Wolfe entitled "Ink Jet Transducer", Ser. No. 317,503, filed Dec. 21, 1972 now abandoned, Application of George J. Fan and Richard A. Toupin entitled "Method and Apparatus for Forming Droplets from a Magnetic Liquid Stream," Ser. No. 429,414, filed Dec. 28, 1973 and Application of Edward F. Helinski and Jack L. Zable entitled "Method and Apparatus for Fast Merging Satellites in an Ink Jet Printing System", Ser. No. **534,043** filed concurrently herewith.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to ink jet recording and particularly to a method and apparatus for generating a stream of drops for use in an ink jet printer.

2. Description of Prior Art

In ink jet recording it is well-known to produce a stream of liquid ink under pressure and to cause perturbations in the stream to make it break up into individual drops which are then directed in a controlled manner onto a record medium to visually record the information. The perturbations can be formed by electromechanical devices which vibrate the jet-forming elements or by the application of external fields to the unsupported jet stream which produce varicosities in the jet stream. U.S. Pat. No. 3,596,275, issued July 27, 1971 to Richard G. Sweet, shows using either a magnetostrictive vibrator or an excitational electrode for producing drops from a conductive ink jet. In U.S. Pat. No. 3,298,030, issued on July 12, 1965 to Arthur M. Lewis and Arling D. Brown, Jr., a piezoelectric transducer is used as the perturbationproducing means. In the previously-mentioned application of George J. Fan and Richard A. Toupin, drops are formed in a magnetic ink jet stream using externally applied magnetic fields at plural uniformly-spaced positions along the stream, the spacing of the fieldproducing elements being equal to the wavelength of the varicosities produced in the stream or a multiple thereof.

One of the problems associated with previous drop generators has been the fact that as the stream breaks up into individual drops there is a tendency for satellites to form. The precise explanation of why satellites form is not fully understood; however, it has been observed that satellite drops, when formed, will usually form from the ligament portions of the jet stream which connect the varicosities produced by the perturbations. It has also been observed that the satellites can have a velocity equal to or different from the adjacent large drops. Depending on the relative velocity of the satellite and large drops merging will take place if their relative velocities are different. The rate at which merging takes place, however, can affect the control of the droplets and the print quality or contamination of the ink jet apparatus.

U.S. Pat. No. 3,683,396, issued Aug. 8, 1972 to Robert I. Keur, Sandra Miller and Henry A. Dahl, attemps to solve the satellite problem by designing the nozzle to have fluid resonance to obtain the formation of fast satellites. The nozzle is designed so that its internal length is determined in relation to the speed of

sound through the fluid in the nozzle and the desired frequency of resonance.

U.S. Pat. No. 3,334,351, issued Aug. 1, 1967 to Norman L. Stauffer, shows a method of merging satellite drops by vibrating the stream to impart a rolling motion to ink drops through the use of dual vibration means operating transverse to and in the direction of flow of the jet stream.

The previously-mentioned application of Joseph P. Pawletko and Bruce A. Wolfe shows a mechanical structure in which two piezoelectric devices operate in different modes on a cantilever beam to prevent formation of satellite drops by imparting a spin thereto.

It will be appreciated that the prior art solutions for eliminating or merging satellite drops require specialized complex structures. Furthermore, such structures lack versatility, since the mechanical devices once designed are strictly confined to specific operating conditions having a very narrow range. As the conditions of the ink and the operating properties of the system vary, the effectiveness of prevention or merging of satellites degrades considerably and the means for controlling the variation in operating conditions becomes complex and costly.

SUMMARY OF THE INVENTION

It is a general object of this invention to provide an improved method and apparatus for producing an ink jet stream comprised of successive ink drops.

It is a more specific object of this invention to provide an improved method and apparatus for controlling the formation of satellites in an ink jet stream.

It is a further object to provide an improved method and apparatus for generating drops from a liquid jet stream in which drops can be generated which are free of satellites.

It is a still further object to provide a method and apparatus for forming drops in an ink jet system which is relatively simple in structure, easy to control, relatively easy to manufacture and operable over a wider range for printing purposes.

The above, as well as other objects, are attained in the practice of this invention by disturbing an ink jet stream in such a way as to cause an asymmetric momentum distribution or velocity variation in the stream. Broadly, in accordance with the invention, the asymmetric momentum distribution or velocity variation in the stream is obtained by applying a periodic force asymmetrical in space and/or time to the fluid stream. In the preferred form in which this invention is practiced, a transducer operated to cause perturbations in a jet stream is energized with an excitation signal having an asymmetrical waveform. A preferred excitation signal includes higher integral harmonics in combination with the fundamental frequency which corresponds with the desired drop rate. Very good control over satellite formation has been obtained using an excitation signal waveform which includes second or second and third harmonics in phase or out of phase with the fundamental frequency in such a manner that the excitation signal has differential rise and fall times.

The transducer can be either electromechanical, such as the piezoelectric crystal attached to a fluid chamber, or a field exciter located adjacent the field controllable jet stream in advance of drop breakoff position. In a specific embodiment in which the invention is practiced, the field controllable jet stream is formed using a magnetic ink such as a ferrofluid. The magnetic ink jet stream is subjected to an asymmetrical field force by exciting an electromagnetic transducer located proximate the jet stream with an excitation signal having an asymmetrical waveform as previously described. The magnetic exciter can be single stage or multiple stage. In the latter case, the stages can be spaced differentially relative to the wavelength of the varicosities in the stream, i.e. the drop wavelength. The asymmetrical field force can also be obtained by structuring the transducer to have a non-uniform gap arrangement through which the stream is projected in which case the excitation signal may have either a symmetrical waveform or asymmetrical waveform depending on what type of satellite control is desired.

Thus, it will be appreciated that great versatility has been provided by this invention. Operation can occur over a wider range thereby greatly facilitating ink jet recording. Using this invention drops can be generated free of satellites and under certain conditions where satellites form, merging can be obtained within the space of a single drop wavelength.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is an isometric view of an ink jet recorder incorporating the drop generator apparatus and method of this invention.

FIGS. 2A – 5C show the force and momentum distribution characteristics for certain waveshapes for explaining the principles of asymmetry as embodied in this invention.

FIGS. 6 – 13 show various waveforms for generating drops free of satellites and for merging in forward or rearward directions in accordance with this invention.

FIG. 14 is a schematic circuit diagram illustrating a drop frequency generator useful for producing the various illustrated waveforms.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings, and particularly FIG. 1, there is shown an ink supply 10 of magnetic ink. The magnetic ink may be any suitable magnetic ink which is preferably isotropic and virtually free of remanence. One suitable example of a magnetic ink is a ferrofluid of the type described in co-pending application of George J. Fan and Richard A. Toupin, entitled "Recording System Utilizing Magnetic Deflection," Ser. No. 284,822, filed Aug. 30, 1972, now U.S. Pat. No. 3,805,272 and assigned to the same assignee as the assignee of this application. Another example of the magnetic ink is a stable colloidal suspension in water of 100 angstrom-sized particles of magnetite (FE_3O_4) with surfactant surrounding the particles.

The ink supply 10 supplies the magnetic ink to a nozzle 11 under a pressure such as 20–50 psi, for example, from which the ink issues as a stream 12 through an opening at the end of the nozzle 11. An exciter 14 is disposed in axial alignment with the path of the stream 12 as it exits from the nozzle 11. The exciter comprises a C-shaped magnetic core 15 having upper pole 16 and a lower pole 17 in mutual vertical alignment above and below the ink jet stream 12. A coil 18 is wound on the arm portions of the C-shaped magnetic core 15 to obtain a maximum flux concentration in the ends of the

magnetic poles. The coil 18 is connected to a drop frequency generator 19 which in accordance with this invention applies a periodic current which produces a magnetic field which produces an asymmetrical field force to cause perturbations in stream 12. The width of each of the pole faces 16 and 17 in the direction of the stream is less than the distance between droplets 22 which are formed by the exciter 14 from stream 12 and preferably is one-half of the wavelength of the perturbations produced in the stream 12 by the exciter plus or minus up to 60%. It is appreciated that this basic dimension may be increased by a length any integral number of wavelengths without a significant deterioration of the operation.

While a single stage exciter is shown in FIG. 1, the present invention includes the use of a dual or multiple stage exciter of the type shown in the co-pending application of E. F. Helinski and J. L. Zable previously mentioned and would in desired conditions utilize the differential spacing to produce outof-phase multiple perturbation field forces along with asymmetry disclosed herein.

The gap between the pole faces 16 and 17 must not be too wide. Otherwise, the magnetic field produced by the current flowing through the coil 18 would not act on the stream 12 in the desired manner to produce the desired perturbations in the stream 12. This is due to the density of the magnetic field decreasing as the gap between the opposed pole faces increases. Similarly, the intensity of the magnetic field also decreases as the gap between the pole faces increases. Thus, the distance across the gap between the pole faces of each pole pair is about 2.5 – 4 times the diameter of the stream. Further details of the relationship of the gaps and magnetic fields may be obtained by reference to the aforementioned application of George J. Fan and Richard A. Toupin. The energization of the coil 18 of magnetic core 15 by the signal generator 19 produces perturbations in the jet stream 12 to cause drops 20 to break off from the stream in a succession of uniformly-spaced drops of substantially uniform size. The stream of ink drops 20 then passes through a magnetic selector 21 having coil 22 which is selectively pulsed by a data signal generator 23 in accordance with a data input to deflect predetermined drops 20 from the original jet stream trajectory to be ultimately caught by a gutter mechanism 24 located in front of the print medium 25. The drops 20 deflected by the selector magnet 21 and those drops not deflected thereby continue to move as a stream through a gap in deflection magnet 26 located in advance of the gutter 24 and print medium 25. A sawtooth signal from raster scan 28 applied to a coil 29 on deflection magnet 26 causes the selected and unselected drops 20 to be deflected vertically. Selected, i.e. the unwanted, drops are caught by the gutter 24 whereas the unselected, i.e. the print drops pass to the right of knife edge 30 of gutter 24 to be deposited on the print medium 25 in accordance with the raster scan signal and the length of time that the individual drops are in the magnetic field generated by the deflection magnet 24. A relative lateral motion is provided between the medium 25 and the jet stream to thereby record information in the form of dot matrix characters or other symbols in a manner which is well-known.

As previously discussed, this invention deals with a method and apparatus for generating drops in which a liquid stream is subjected to an asymmetrical perturbation force. To illustrate the phenomenon reference is made to FIGS. **2A, 2B** and **2C.** As seen in FIG. **2A,** a perfectly symmetrical (or anti-symmetrical) current waveform such as square wave **32** is applied by the drop frequency generator **19** of FIG. **1** to exciter **14.** The spatial distribution of magnetic force (which is approximately a linear function of current level) by a dual stage magnetic exciter, for example, having uniform gaps and a distance between midpoints **33** and **34** equal to a wavelength is shown in FIG. **2A.** The spatial force distribution, curve **37,** is antisymmetric about point **31.** This force distribution with waveform **32** results in the velocity variation of the moving stream shown by curves **38** in FIG. **2C** and is perfectly antisymmetric about the points where drops are formed. This results in satellites **39** and parent drops **40** which are perfectly stable since the integrated momentum for the drops is zero.

FIGS. **3A** – **3C** show the case in which asymmetry is obtained. In FIG. **3A** a distorted current waveform **41** is applied to a dual stage exciter having poles **35** and **36** which have a uniform gap and are spaced along the stream a distance equal to the wavelength of the drops to be formed. In this case the spatial distribution of magnetic forces about point **31** is still anti-symmetrical. However, the resultant momentum distribution is skewed, as seen from exaggerated curve **43** in FIG. **3C,** due to the time dependent asymmetric variation in force amplitude in accordance with the energizing waveform **41** while the stream is passed through the exciter. In this case the parent drops **40** form in stable position, but the satellites **39** are unstable and accelerate toward the parent drops.

As seen in FIGS. **4A** – **4C,** the spatial distribution of the magnetic forces is skewed by altering the exciter structure by the provision of nonuniform field gaps. In this case a symmetrical square wave **32** (FIG. **4A**) is used to energize the dual pole exciter. The poles **44** and **45** have non-uniform gaps **46** and **47** tapered in the upstream direction. The spatial distribution of magnetic forces, as shown by curve **48** in FIG. **4B,** is no longer anti-symmetrical but has become asymmetrical. The result is to produce an asymmetrical momentum distribution in which the satellites **39** are unstable and accelerate toward the parent drops **40,** as seen by the velocity curve **49** in FIG. **4C.** In the case of FIGS. **4A** – **4C,** asymmetry is produced solely by the structure of non-uniform gaps while the energizing current remains symmetrical.

In FIGS. **5A** – **5C** the combined effects of distorted waveform energization (curve **41** in FIG. **5A**) and non-uniform air gaps (**46** and **47** in FIG. **5B**) for the poles (**44** and **45** in FIG. **5B**) of a dual stage exciter, are shown. As illustrated by curve **50** in FIG. **5B,** the spatial distribution of magnetic forces have become asymmetrical. In addition, the variation in the force amplitude while the stream is passed through the exciter results in a skewing of the momentum distribution, as shown by curve **51** in FIG. **5C,** which causes the satellites **39** to be unstable and accelerate toward the parent drops **40.**

While certain specific structural forms are shown in relation to a dual stage magnetic exciter, it is understood that the same structural forms are applicable to the single stage magnetic exciter or other types of multi-stage magnetic exciters. Also, single stage or multi-stage exciters can be modified to have other forms or excited by other waveforms to produce asymmetrical perturbation field forces which cause fast satellite merging or satellite free drop formation. For example, the dual stage exciter of FIGS. **2** – **5,** as well as other multi-stage exciters, might have successively different non-uniform gaps to produce the force skewing and momentum skewing described above.

Various asymmetric waveforms can be used which produce satellite-free drop formation or fast merging of satellites. In FIG. **6** the current waveform **55** having a peak amplitude of 0.5 amperes and a frequency of 30.8 KHz was applied to a single stage exciter **14** having a uniform gap of 6 mils. The width of the pole was 5 mils. A ferrofluid ink was applied at the pressure of 36 psi to a nozzle with a 2.5 mil diameter, resulting in a drop distance of 17.5 mils. Arrow **56** indicates the direction of flow of the jet stream. As seen, drop **57** has detached from the ligament portion **58** of the continuous jet stream **12** with a forward ligament **59** attached thereto. Within the distance of one drop wavelength the ligament portion has substantially disappeared into the main drop portion.

As seen in FIG. **7,** satellite **60** will form ahead of drop **61** and then merges with drop **61** within a single drop wavelength. The exciter of FIG. **7** was the same as for FIG. **6** except that the amplitude of the current waveform **62** was approximately 0.25 amperes. Thus, in an actual machine environment when a fluctuation or temporary change in the power supply condition causes the power applied to the exciter to become reduced, the print quality of the ink jet printer will not be significantly degraded, since while satellites might form, merging occurs in a very short space so that substantially the same drop dynamics are encountered and satellites present do not affect print quality.

In FIG. **8** the waveform **63** is a fast rise, slow fall current waveform, with an amplitude of 0.5 amperes. The single stage exciter of FIGS. **6** and **7** was used with substantially the same operating conditions. As seen in FIG. **8,** the ligament portion **64** does not break off separately, but remains attached to the rear of drop **65** at breakoff and almost disappears within one drop wavelength.

In FIG. **9,** the fast rise, slow fall waveform **66** had an amplitude of 0.4 amperes. Otherwise, the conditions and structure remain the same as for FIG. **8.** In this case, the drop formation is also satellite free. However, it is to be observed that the connection of the ligament portion **64** to drop portion **65** is less secure and it is expected that with a lower amplitude current satellites would probably form. However, due to the asymmetrical force caused by the asymmetry of the waveform **66** fast merging within one drop wavelength can be expected.

It is also to be noted from the above specific examples that by changing the waveform from slow rise to fast rise the direction of merging of attached ligament or satellite is changed.

In FIGS. **10** and **11** the same waveforms **55** and **62,** as used in FIGS. **6** and **7,** are used at an applied frequency of 32.2 KHz with a dual stage magnetic exciter. The width of the poles was **9** mils and the pole gap was approximately 6 mils and the separation from the poles was 15 mils. Ferrofluid ink was supplied at a pressure of **36** psi to a 2.5 mil diameter nozzle, resulting in drop distance of 15 mils. As seen in FIG. **10,** the ligament portion **64** remains attached to the rear of the drop portion **65** to provide a satellite-free drop formation. In FIG. **11,** the ligament portion breaks off to the rear of the drop portion to form satellites **68** which are merged with drops **69** within three drop wavelengths. It is apparent from FIGS. 10 and 11 that an increase in amplitude current from 0.2 amperes or waveform 62 would reduce the merge distance or eliminate satellite formation.

In FIGS. 12 and 13 substantially the same fast rise, slow fall waveforms 63 and 66 of FIGS. 8 and 9 were used with a dual stage exciter of FIGS. 10 and 11 operated with substantially the same conditions. As seen in FIG. 11, the ligament portion 70 forms ahead of the drop portions 71 upon breakoff from the stream 12. In FIG. 13 the ligament portion forms a satellite 72 which merges with drop 73 within three drop wavelengths. As in previous case with a single stage exciter, changing the current waveform from the slow rise to fast rise produced a change in direction of ligament formation for satellite merging.

Various other asymmetrical waveforms can be used to produce satellite-free drop formation or fast merging. From the above examples it can be seen that the preferred asymmetrical waveform takes the form of sawtooth with essentially a linear ramp. Such a signal essentially has a waveform comprising a fundamental frequency and higher harmonics. The specific waveform 55 has a harmonic content in which the approximate ratio of the second harmonic to the fundamental $a2/a1 = 0.5$ and the ratio of the third harmonic $a3/a1 = 0.33$, where the equation of the idealized sawtooth waveform is expressed as follows:

$$f(t) = a_0 + \sum_{n=1}^{\infty} a_n \sin \frac{2\pi nt}{T}$$

In the case of waveform 66 (see FIG. 9) the approximate ratio $a2/a1$ was 0.24 and the ratio $a3/a1$ was equal to 0.11. Harmonics higher than the third may also be present in the sawtooth waveforms illustrated. Their effect on asymmetry is considered to be generally negligible. Other combination of harmonics and fundamentals may be used. However, the best results are obtained if the composite asymmetrical waveform produced has a rise time substantially different from the fall time. By controlling these differences and with proper construction of exciters, it is possible to control the direction of ligament breakoff and merging when satellites form as previously illustrated.

Various drop generator circuit devices might be used for generating the waveforms practiced with this invention.

In FIG. 14, a periodic signal from a pulse generator 80 passes through a pulse width control circuit 81 to operate a switch 82 for controlling the charge and discharge of capacitor 83. The frequency of the signal from pulse generator 80 corresponds with the desired perturbation and drop rate in stream 12. The pulse width is regulated by pulse width control circuit 81 and controls the duty cycle of the coil 18. Positive and negative current sources 84 and 85, respectively, the magnitudes of which I_o and I_i, are controlled by variable resistors 86 and 87 in such a way that current I_o never exceeds current I_i. Diodes 88 and 89 maintain the input voltage V_{IN} within a predetermined upper and lower voltage values. During an on portion of switch 82, the current difference (I_i-I_o) determines the charging rate of capacitor 83 and controls the slope of the rising voltage (i.e. the rise time) of signal 90 while in the off portion of switch 82 the current I_o controls the discharge rate and, thus, the slope of the falling voltage (i.e. the fall time) of the input signal 90. A transconductance amplifier 91 converts the voltage in signal 90 into an output current signal 92 of the same form as signal 90. The coil 18 of exciter 14 is connected to a supply voltage E_o which is set to exceed the maximum inductive potential of the exciter 14. The amplitude of the current waveform 92 can be controlled by altering the gain of the transconductance amplifier 91 or by varying the level of the input voltage V_{IN}. The rise and fall time of the voltage signal 90 and the current signal 92 is controlled by controlling the on-off times of switch 82 through the regulation of the pulse width control circuit 81.

Thus, it will be seen that an improved method and apparatus have been provided for generating drops from a liquid stream in which the individual drops can be readily formed free of satellites or satellites, if formed, can be fast merged. A wide range of choices for operation is also provided in accordance with this invention and can be operated under a wide range of conditions in an actual jet printing apparatus. By providing satellite-free drop formation and fast merging of satellites improved drop dynamics is obtained and the control of the drops for deflection to trajectories to form characters is greatly simplified for improving print quality in an ink jet recorder.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

We claim:

1. In an ink drop forming system of the type having means for supplying ink under pressure to a nozzle or the like to cause a continuous jet stream of ink to flow from said nozzle, and a transducer for causing periodic perturbations in said stream at a predetermined frequency whereby drops are formed in said jet stream, the improvement comprising,

a method of controlling the formation of satellites by energizing said transducer with a signal having an asymmetrical waveform.

2. In an ink drop forming system of the type in accordance with claim 1, the improvement further comprising energizing said transducer with an asymmetrical waveform having a fundamental frequency and higher harmonics.

3. In an ink drop forming system of the type in accordance with claim 2, the improvement further comprising energizing said transducer with an asymmetrical waveform in which the higher harmonics includes at least the second harmonic.

4. In an ink drop forming system of the type in accordance with claim 3 in which the ratio of the amplitude of the second harmonic to the fundamental frequency is at least equal to 0.5.

5. In an ink drop forming system of the type having means for supplying magnetic ink under pressure to a nozzle or the like to cause a continuous jet stream of magnetic ink to flow from said nozzle and magnetic transducer means for forming periodic perturbations in said stream, the improvement comprising:

said transducer having means for generating an asymmetrical force field at a predetermined frequency in the vicinity of a segment of said jet stream for controlling the formation of satellites produced by said periodic perturbations.

6. In an ink drop forming system of the type in accordance with claim 1 in which

said transducer means comprises a magnetic core device disposed proximate at least one segment of said stream,

said core device being structured to produce an asymmetrical force field on said segment of said stream, and

means for periodically energizing said magnetic core device at said predetermined frequency in timed relation with the flow of said stream relative to said magnetic core device.

7. In an ink drop forming system of the type in accordance with claim 6 in which

said magnetic core device includes pole portions disposed proximate said segment of said stream, and

said pole portions forming a non-uniform gap along said segment of said stream.

8. In an ink drop forming system of the type in accordance with claim 7 in which

said pole portions are tapered in the direction of said stream flow to form said non-uniform gaps.

9. An ink drop system of the type in accordance with claim 5 in which

said magnetic transducer means comprises a magnetic core device disposed to produce a magnetic field proximate at least one segment of said stream, and

means for periodically applying an energizing signal at said predetermined frequency to said magnetic core device,

said energizing signal having an asymmetrical waveform.

10. In an ink drop forming system of the type in accordance with claim 9 in which

said energizing signal contains harmonics higher than one for producing said asymmetrical waveform.

11. In an ink drop system of the type in accordance with claim 9 in which said higher harmonics includes a second harmonic.

12. In an ink drop system in accordance with claim 10 in which said higher harmonics are out of phase with the fundamental frequency of said signal.

13. In an ink drop system in accordance with claim 9 in which

said signal has a long rise time relative to its fall time.

14. In an ink drop system of the type in accordance with claim 9 in which

said signal has a short rise time relative to its fall time.

15. In an ink drop forming system of the type having means for supplying field controllable ink under pressure to a nozzle or the like to cause a continuous jet stream of ink to flow from said nozzle, and transducer means for forming periodic perturbations in said stream, the improvement comprising:

said transducer means having means for generating an asymmetrical force field at a predetermined frequency in the vicinity of a segment of said jet stream for controlling the formation of satellites produced by said periodic perturbations.

16. In an ink drop forming system of the type having means for supplying ink under pressure to a nozzle or the like to cause a continuous jet stream of ink to flow from said nozzle, and transducer means for forming periodic perturbations in said stream, the improvement comprising:

said transducer means having means for applying an asymmetrical force at a predetermined frequency to said jet stream for controlling the formation of satellites produced by said periodic perturbations.

17. In an ink drop forming system of the type having means for supplying ink under pressure to a nozzle or the like to cause a continuous jet stream of ink to flow from said nozzle

means for forming drops in said stream comprising in combination,

a transducer for causing periodic perturbations in said stream at a predetermined frequency, and

means for energizing said transducer with a signal having an asymmetrical waveform.

18. In an ink drop forming apparatus in accordance with claim 17 in which said signal has a sawtooth waveform.

19. In an ink drop forming apparatus in accordance with claim 18 in which said sawtooth waveform has a slow rise time and a fast drop time.

20. In an ink drop forming apparatus in accordance with claim 18 in which said sawtooth waveform has a fast rise time and a slow drop time.

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Disclaimer

3,928,855.—*Edward F. Helinski*, Johnson City, and *Ho C. Lee*, Endicott, and *Jack L. Zable*, Vestal, N.Y. METHOD AND APPARATUS FOR CONTROLLING SATELLITES IN AN INK JET PRINTING SYSTEM. Patent dated Dec. 23, 1975. Disclaimer filed July 3, 1978, by the assignee, *International Business Machines Corporation*.

Hereby enters this disclaimer to claims 1, 2, 3 and 17 of said patent.

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