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(71) Applicant: VIDEOJET SYSTEMS INTERNATIONAL, INC.
2200 Arthur Avenue
Elk Grove Village Illinois 60007(US)

(72) Inventor: Pickell, James Robert
1191 Independence
Barlett, Illinois(US)
Inventor: Keur, Robert Irving
7138 Lill Street
Niles, Illinois(US)
Inventor: Clark, James Eugene
736, Thornapple Drive
Naperville, Illinois(US)

(74) Representative: Loven, Keith James et al
GEC plc Patent Dept.(Chelmsford Office)
GEC-Marconi Research Centre West
Hanningfield Road
Great Baddow Essex CM2 8HN(GB)

(54) **Nozzle drive control system and method for ink jet printing.**

(57) A drive control system is disolosed which automatically maintains nozzle drive voltage within a proper range. The control system monitors the state of the "intermediate satellites" positioned between ink drops used for printing. When these satellites are neither forward nor backward merging, a first cardinal point designated C(L) is identified. A second cardinal point, C(H), is determined when the drop breakoff point stops decreasing, relative to said nozzle, with increasing nozzle drive voltage. From the two cardinal values, a desired operating range for a particular ink can be computed and the control system automatically set. The computed value is essentially independent of temperature.

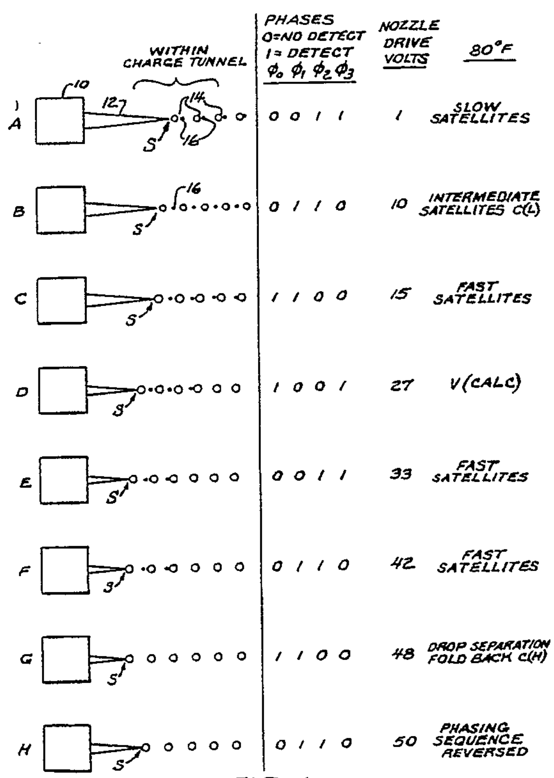

FIG. 1

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NOZZLE DRIVE CONTROL SYSTEM AND METHOD FOR INK JET PRINTING

This invention relates to ink jet printing systems and similar drop marking systems in which a supply of electrically conductive ink is provided to a nozzle. The ink is forced through a nozzle orifice while at the same time an exciting voltage is applied to the nozzle to cause the stream of ink to break into droplets which can be charged and deflected onto a substrate to be marked. Such ink jet technology is well known and, for example, see U.S. Patent Nos. 4,727,379 and 4,555,712.

To ensure proper operating conditions for consistent printing quality, the exciting energy or voltage applied to the nozzle must be properly set during operation of the system. Presently, most ink jet printers require manual setting of the energy applied to the ink stream as it exits the nozzle. The appropriate value is either empirically determined by comparing what is seen to an existing diagram or by determining the drop separation point and comparing it with machine specifications. In either case, the resulting print quality varies.

Efforts to provide automatic control of the modulation voltage have concentrated on detecting separation point position, relative to a fixed location, such as the charge tunnel. See, for example, published European patent specification EPA 0287373. Another approach is disclosed in U.S. Patent No. 4,638,325 which utilizes a small charging electrode and a downstream electrometer by which the drop separation point can be determined by observing the current at the electrometer as the separation point approaches the small electrode. In the '325 patent, the maximum current is produced when drop separation is closest to the small charging electrode.

The above method does not take into account the basic reason for maintaining consistent drop charging conditions. The drop separation point varies greatly with the surface tension and viscosity of the ink, therefore, simply holding the separation point constant still results in different satellite conditions and variable print quality. In short, maintaining the drop separation point constant is not a satisfactory solution to the problem.

What is desired is a system which can determine a range of proper printing nozzle drive voltages and then compute a satisfactory intermediate value within said range. Such a system should be temperature independent over a wide range of operating temperatures to result in a significantly better control system.

It is accordingly an object of the present invention to provide such a nozzle drive control system which improves upon known techniques.

It is a further object of the invention to provide a nozzle control system which can accurately monitor the condition of the satellite drops and the drop breakoff point and compute therefrom a satisfactory range of nozzle drive voltages for operating an ink jet printer.

A further advantage of this invention is that it allows automation of the nozzle voltage for best quality printing using a continuous ink jet printer regardless of ink type and temperature. This invention avoids problems with recombining satellites that occur when holding the drop separation point constant while ink type and temperature vary. These cause unwanted charge variations because a satellite which carries part of the charge of its parent charged drop will transfer that charge to the drop following when merging occurs. These and other objects of the invention will be apparent from the remaining portion of this specification.

Figure 1 illustrates the principles of ink jet drop formation useful in understanding the present invention.

Figure 2 is a software flow diagram illustrating the manner in which the processor of the present invention operates.

Figure 3 is a circuit diagram illustrating the control circuit according to the present invention.

Figure 4 is a graph useful in explaining the operation of the present invention.

Figure 5 illustrates the manner in which intermediate satellites may be detected.

Figure 6 is a timing diagram useful in explaining the test pattern used for detecting the upper cardinal point.

Referring to Figure 1, there are a series of nozzles shown. The nozzle 10 emits therefrom a stream of ink 12. A nozzle drive voltage is applied which voltage causes the stream to break up into a series of discrete drops 14. Smaller drops, known in this art as satellites, form between the drops 14. The satellites 16 behave in a manner which is a function of the energy applied to the nozzle (measured in terms of the nozzle voltage).

Referring to Figure 1, when the applied acoustic power to the ink stream is low, the natural behavior of the satellites is to form independently of the drops and then fall back and merge with the drops which follow. This is referred to as rearward merging satellites or slow satellites and is illustrated in Figure 1A. The fall back and merging occurs in approximately ten drop periods depending upon the physical parameters of the ink (viscosity, surface tension, specific gravity, etc.).

As the drive to the nozzle is increased, a point, designated herein as C(L), will occur. This term refers to a lower cardinal point. Cardinal is a term borrowed from optics terminology where it denotes an important point of a lens system, i.e., a focal point, a nodal point, or a principal point. For purposes of the present specification, C(L) is an important point because it represents the point at which the satellites separate from the leading and the following drops at the same time (see Figure 1D). Surface tension forces pull these satellites forward and backward with equal force. The result is that the satellites stay at a mid or intermediate point between the drops as they travel through space. It is this condition, referred to as C(L), that can be detected at a downstream point by detecting the satellites and the drops. At the point C(L) there will be a doubling of the normal drop frequency which can be detected. In all other cases, the satellites will have merged with either the leading or the trailing drops. Appropriate detectors are illustrated and described in connection with Figure 5 of this disclosure.

Virtually all nozzles used for ink jet printing systems exhibit such intermediate satellites which are neither forward nor rearward merging. The point C(L) will be detected by frequency doubling as the power to the nozzle drive is increased from a low level to a level just adequate to form intermediate satellites.

In one embodiment of the Figure 5 detector, an appropriate test signal is placed on a charging electrode so that both the drops and the intermediate satellites will be charged. The sensed drop frequency will double when intermediate satellites are present and pass the sensor. Alternatively, an optical detector may be employed which does not require charging of the drops and satellites but will detect a doubling in the number of drops passing the detector.

In either case, the detector is positioned a sufficient distance downstream from the nozzle orifice to permit the satellites to merge.

In addition to a lower cardinal point, C(L), most ink jet nozzles also exhibit what can be designated as an upper cardinal point, C(H). This point can be observed by slowly increasing the power to the nozzle and observing the point of drop separation. As the power to the nozzle is increased from a low level (Figure 1A), the drop separation point, designated S, moves closer to the nozzle until it reaches (Figure 1G) its minimum distance from the nozzle. This is designated the upper cardinal power point C(H). Thereafter, the breakoff point moves away from the nozzle (Figure 1H). This fold back or reversal can be sensed by appropriate circuitry and software. A description of the circuitry and methodology for detecting the upper cardinal point C(H) is provided in connection with a description of Figure 3.

First, however, with reference to Figure 4, there is shown a graph which demonstrates the characteristics of a typical ink used in an ink jet printing system. This ink, manufactured by the assignee of the present invention, and designated 16-8200, was utilized with a nozzle of the type described in U.S. Patent No. 4,727,329, which patent is hereby incorporated by reference. The cross hatched area on the graph represent nozzle drive voltages that produce good quality printing over a temperature range of approximately 40 degrees F to 110 degrees F. The lower and upper cardinal power points, C(L) and C(H), are also plotted for the same nozzle and ink composition. From this information, it is possible to calculate a voltage value, V(calc), from the following equation:

V(calc) = alpha [C(L) + C(H)] /2 EQ 1

where alpha is a function of the ink described hereafter.

Values of V(calc) calculated from the foregoing equation are plotted in Figure 4. These values of V-(calc) all lie within the cross hatched area of the graph and represent nozzle drive voltages that produce quality printing.

Referring to Figures 1 and 3, circuitry suitable for practicing the invention will be described. The nozzle 10 is connected to an ink supply 32 via an ink conduit 34. The ink stream is grounded intermediate the ink supply and nozzle 36. The nozzle has an acoustic energy applied to it, as for example, by means of a piezo-electric device as disclosed in the aforementioned U.S. patent 4,727,379. The drive voltage for the piezo-electric device is provided from a nozzle drive amplifier 38 via line 40. In turn, the amplifier is controlled by a processor 42, such as a microcomputer, via a digital to analog converter (D/A) 44. The controller 42 also operates charge amplifier 44 via D/A 46 to control the voltage applied to the charge tunnel 48. As is well known in this art, the charge tunnel 48 is disposed downstream of the nozzle 10 in the region where the drops are intended to form as the stream of ink breaks up into drops and satellites. In this manner selected drops can be charged for deflection onto a substrate or, if left uncharged, returned by way of a gutter to the ink supply 32.

According to the present invention, the controller 42 receives input signals from a capacitive pickup 50 downstream of the charge tunnel. The signal from the pickup 50 is provided to a preamplifier 52 and to a band pass filter 54 (a notch filter designed to pass a frequency equal to twice the normal drop frequency of the ink jet system). Thus, the capacitive pickup 50 detects the point C(L) in which the drop frequency has doubled due to the presence of intermediate satellites (Figure 1B). That signal, analogue in nature, is passed by the filter 54 to a comparator 56 which provides a digital output when the input exceeds a threshold. This signals the controller that C(L) has been detected. The controller thus stores the corresponding nozzle drive voltage valve.

The second input of interest to controller 42 provides a signal indicating the occurrence of C(H), the fold back point illustrated in Figure 1G. This signal is produced on line 58 from a pickup 60 in electrical communication with the electrically conductive ink stream. The output of pickup 60 is provided to an integrating preamplifier 62 which, in turn, is provided to a comparator 64. As will be described, if the charge on the capacitor associated with preamplifier 62 exceeds a threshold set for comparator 64, a digital output is provided on line 58 to the controller.

To understand the function of the comparator 64, it is necessary to refer to Figures 1, 3 and 6. To determine C(H), a test signals are placed on the charge tunnel 48 for a period equal to 30 drop times. For example, the signal denoted Test Video 0 in Figure 6. The wave form illustrated in Figure 6 is referenced to the drop clock wave form which may be, for example, 66 kilohertz. During the time that the test video 0 signal is high, the charge tunnel 48 attempts to apply a charge to each ink drop formed as the droplets break off from the ink stream. During this period the pickup 60 will detect whether or not the drops are successfully charged. For each drop which is charged an incremental charge is stored on the capacitor associated with the preamplifier 62. If most of the drops are successfully charged by the test video signal, the voltage from the preamplifier will exceed the threshold set on the comparator 64 and signal the controller. This sequence is then repeated for test video signals 1, 2, and 3, all of which are illustrated in Figure 6. Each test pattern is a quarter lambda out of phase from the preceding test pattern (where lambda is the droplet spacing). As a result, it is possible to accurately determine the location (in quarter lambdas, for example) of the droplet breakoff point relative to the positions of the two cardinal points.

The result of this operation is illustrated in Figure 1 where there is shown for each of Figures 1A-H a four bit binary code representing the results of applying the test video signals 0 through 3. Thus, for example, with respect to Figure 1B, test video 1 and test video 2 are digital ones, while test video 0 and test video 3 are zero indicating that the latter two test videos did not result in charging of the droplets (This is due to the phase of the test video signals relative to the drop clock).

As the drive voltage to the nozzle increases, the pattern of the successfully charged drops changes as indicated in Figure 1 in a predictable sequence based upon the phasing of the test video signals. At the cardinal point C(H), however, there is a first phase reversal (additional phase reversals may occur at higher drive voltages). That is, instead of the expected phase pattern 1001 for Figure 1H, the pattern 0110 is observed, which pattern is exactly the same as Figure 1F. Thus, the circuit accurately detects C(H) the first fold back point where drop breakoff within the charge tunnel 48 is at a minimum distance from the nozzle.

In practice, the comparator 64 is preferably sampled only once, at about 15 drop times after the start of each test video signal. The output from the comparator is a one or zero indicating that the drops were or were not successfully charged.

It will be recognized from the review of Figure 6 that the four test video signals have a pulse width of approximately 66% of the drop time and that each test video signal is one-quarter drop time out of phase with every other test video signal. The phasing sequence ends after the output of the comparator is recorded for the four video test signals.

As can be seen from Figure 1, the drop separation point occurs earlier (nearer to the nozzle) as nozzle voltage increases. This is recognized by the detector as indicated by the pattern of ones marching from right to left in Figures A through G (and wrapping around). This continues until the fold back point, C(H) where the sequencing reverses itself and the detector signals this voltage value to the controller.

While the Figure 3 embodiment shows separate pickups for C(L) and C(H), it will be recognized by those skilled in the art that the capacitive pickup 50 can be used for both purposes. That is, the pickup 50 can detect the C(L) value and, by connecting preamp 60 and comparator 64 to the capacitive pickup, it can also detect C(H). Thus, it is not necessary to use a separate pickup 60 behind the nozzle since the capacitive pickup 50 downstream of the charge tunnel can, if desired, perform both functions.

It will be recognized by those skilled in the art that if a separate pickup 60 is utilized for detecting C(H) it is then possible to use an optical or an acoustical pickup in place of the capacitive pickup 50 to detect C(L). The advantage of using an optical or acoustical pickup is that the drops do not have to be charged to be detected.

When the controller has received the information necessary to determine C(L) and C(H), it employs equation one to calculate V(calc). Figure 2 illustrates a software flow diagram suitable for performing the calculations according to the present invention. It is important to note that knowledge of the ink temperature is not necessary for a determination of a proper nozzle drive voltage.

Referring to Figure 2, determination of the cardinal points will be described. The controller 42, in the case where a capacitive pickup is utilized, sets the charge tunnel voltage to a constant value. It then sets the nozzle drive voltage to a minimum value via line 40. Nozzle drive voltage is slowly increased and the capacitive pickup is checked to determine if frequency doubling has occurred. If not, voltage increases, in small increments, until frequency doubling is detected. As indicated previously, frequency doubling indicates the condition where intermediate satellites, which are not merging, are being formed. When frequency doubling, is detected, the value of the nozzle drive voltage is recorded as C(L).

The controller then initiates the phase control portion of its routine to detect C(H). The test video signals shown in Figure 6 are applied to the charge tunnel electrode. The sensor 60, or alternatively the capacitive pickup 50, is monitored to detect whether drops have been successfully charged for each of the four test signals. The software then checks to detect whether or not phase reversal has occurred. If not, the nozzle drive voltage is increased, in small increments, until phase reversal is detected. Upon detection, the nozzle drive voltage is recorded as C(H).

Upon obtaining values of C(H) and C(L), the value V(calc) is computed. This value V(calc), which is shown in Figure 4 is in the middle of the desirable operating range of the system and is thereafter used as the nozzle drive voltage. In summary form, this operation may be stated as follows:

I. A.Assuming an electrical charge detector, begin by applying a constant charge voltage to the charging electrode (charge tunnel).

B. Increase the applied nozzle drive voltage slowly from a low level, i.e., less than 9 volts, sine wave, peak-to-peak.

C. Monitor the downstream detector for a frequency twice that of the drop frequency, that is, search for intermediate satellites.

D. Once the doubled frequency is detected, record the voltage level as the lower cardinal power point C(L).

II. A. Switch to the phasing system and apply sequential phasing voltages to the charging electrode.

B. Observe the sequential direction of "good" phase (in our example "1"s) as nozzle drive voltage is increased.

C. Record the nozzle voltage as C(H) when the direction or sequence of the good phase reverses.

D. Calculate the proper drive voltage from eq(1) for the ink and apply it the nozzle.

Referring again to equation one, it will be noted that the calculation of the value V(calc) requires a value alpha be specified which is ink dependent. This value alpha can be determined as follows. Since the good printing region lies sandwiched between the lower and upper cardinal power points (see Figure 4) an acceptable solution would be to set alpha = 1. This would locate V(calc) midway between C(L) and C(H), however, some added tolerance may be gained by choosing slightly smaller or slightly larger values. A smaller alpha would lower V(calc) and a larger alpha would raise V-(calc). It is desirable to adjust alpha for each ink to optimize its printing range. This can easily be done by calculating V(calc) for a specific alpha and plotting the results on a graph representing the desirable range of a particular ink. In other words, if desired, alpha may be empirically optimized for each ink composition.

The desirable portion of the range shown in Figure 4 can also be accessed by using only one of the cardinal power points. For example, the following equations can be used for calculating a nozzle drive voltage that will produce good printing from the lower or the higher cardinal points:

$V(L) = C(L) + E_1$ EQ 2

$V(H) = C(H) - E_2$ EQ 3

where:

E_1 = 15 volts

E_2 = 20 volts

E_1 and E_2 are voltages empirically determined from the good printing range of a particular ink. For example, in Figure A, C(L) is about 10 volts. V(calc) is about 25 volts. Therefore, if E_1 is selected as 15 volts, it will reliably apprixmate v(calc) when used in EQ 2. Both V(L) and V(H) will lie within the cross hatched area on the graph in Figure 4.

Claims

1. A control circuit for setting the exciting voltage applied to the nozzle of an ink jet printer to break a steam of ink into droplets, comprising first detecting means for detecting the exciting voltage C(L) at which intermediate satellite droplets are produced by the nozzle as the exciting voltage is slowly increased from a minimum, second detecting means for detecting the exciting voltage C(H) at which the droplet breakoff point is a minimum distance from the nozzle as the exciting voltage is slowly increased from C(L), and calculating means for calculating from the voltages C(L) and C(H) the exciting voltage to be used for printing.

2. A control circuit according to Claim 1, wherein the first detecting means includes a capacitive pickup downstream of the nozzle to detect the electrically charged droplets.

3. A control circuit according to Claim 1, wherein the first detecting means include an optical detector located downstream of the nozzle, the

detector detecting the droplets passing the detector.

4. A control circuit according to Claim 2 or 3, wherein the first detecting means further includes circuit means for providing an output signal to the calculating means when the detected droplet frequency doubles.

5. A control circuit according to any preceding claim, further including means for applying electrical test patterns to the droplets, the patterns varying in phase relative to the droplet timing whereby only some of the test patterns successfully charge the droplets, and wherein the second detecting means includes a pickup to detect which of the droplets have been charged, and the calculating means includes means for determining the C(H) value from the change in the sequence of charge patterns.

6. A control circuit according to Claim 5, wherein the means for applying the test patterns include a charge amplifier and a charge tunnel positioned downstream of the nozzle in the region of droplet formation.

7. A control circuit according to any preceding claim, wherein the calculating means calculates the exciting voltage for printing according to the equation:

V(CALC) = alpha[C(L) + C(H)]/2

where alpha is a value related to the ink.

8. A method of determining the exciting voltage to be applied to the nozzle of an ink jet printer to break a stream of ink into droplets for printing, comprising the steps of:

(a) slowly increasing the exciting voltage from a minimum;

(b) detecting and recording the voltage C(L) at which the droplet frequency doubles due to the formation of intermediate (non-merging) satellite droplets;

(c) detecting and recording the voltage C(H) at which droplet formation first occurs closest to the nozzle; and

(d) calculating from the voltages C(L) and C-(H) the exciting voltage for printing.

9. A method according to Claim 8, wherein the exciting voltage for printing is calculated from the equation:

V(CALC) = alpha[C(L) + C(H)]/2

where alpha is a value related to the ink.

10. A method according to Claim 8 or 9, wherein the voltage C(L) is detected by detecting the charges on the droplets sufficiently downstream of the nozzle to eliminate the presence of merging satellite droplets.

11. A method according to Claim 8 or 9, wherein the voltage C(L) is detected by optically detecting the droplets sufficiently downstream of the nozzle to eliminate the presence of merging satellite droplets.

12. A method according to any of Claims 8 to 11, wherein the voltage C(H) is detected by:

(i) applying electrical test patterns to the droplets, the patterns varying in phase relative to the droplet timing whereby only some of the test patterns will successfully charge the droplets;

(ii) detecting which droplets have been successfully charged; and

(iii) determining the voltage C(H) from the change in the sequence of charge patterns.

13. A method of determining the exciting voltage to be applied to the nozzle of an ink jet printer to break a stream of ink into droplets for printing, comprising the steps of:

(a) slowly increasing the exciting voltage from a minimum;

(b) detecting and recording the voltage C(L) at which the droplet frequency doubles due to the formation of intermediate (non-merging) satellite droplets; and

(c) estimating the exciting voltage for printing according to the equation:

V(est) = C(L) + E

where E is a voltage related to the performance of the ink.

14. A method of determining the exciting voltage to be applied to the nozzle of an ink jet printer to break a stream of ink into droplets for printing, comprising the steps of:

(a) slowly increasing the exciting voltage from a minimum;

(b) detecting and recording the voltage C(H) at which droplet formation first occurs closest to the nozzle; and

(c) estimating the exciting voltage for printing according to the equation:

V(est) = C(H) - E

where E is a voltage related to the performance of the ink.

15. A control circuit for determining the exciting voltage to be applied to the nozzle of an ink jet printer to break a stream of ink into droplets for printing, comprising means for detecting and recording the voltage C(L) at which droplet frequency doubles due to the formation of intermediate (non-merging) satellite droplets as the exciting voltage is slowly increased from a minimum, and means for estimating the exciting voltage for printing according to the equation:

V(est) = C(L) + E

where E is a voltage related to the performance of the ink.

16. A control circuit for determining the exciting voltage to be applied to the nozzle of an ink jet printer to break a stream of ink into droplets for printing, comprising means for detecting and recording the voltage C(H) at which droplet formation

first occurs closest to the nozzle as the exciting voltage is slowly increased from a minimum, and means for estimating the exciting voltage for printing according to the equation:

V(est) = C(H) - E

where E is a voltage related to the performance of the ink.

17. A circuit for determining the exciting voltage to be applied to the nozzle of an ink jet printer to break a stream of ink into droplets for printing, comprising means for slowly increasing the exciting voltage from a minimum, means for detecting and recording the voltage C(L) at which droplet frequency doubles due to the formation of intermediate (non-merging) satellite droplets, means for detecting and recording the voltage C(H) at which droplet formation first occurs closest to the nozzle, and means for calculating the exciting voltage for printing according to the equation:

V(CALC) = alpha[C(L) + C(H)]/2

where alpha is a value related to the ink.

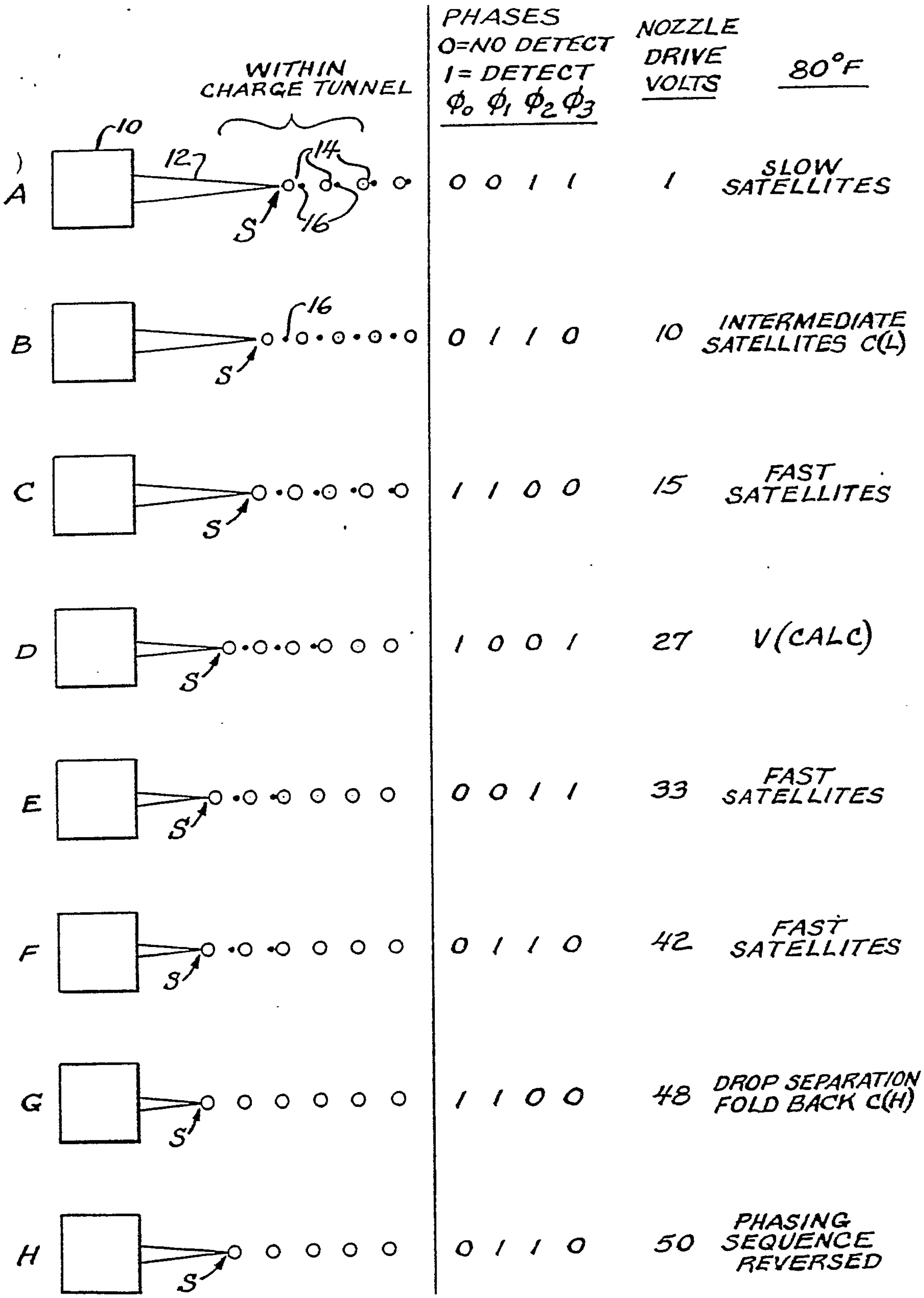
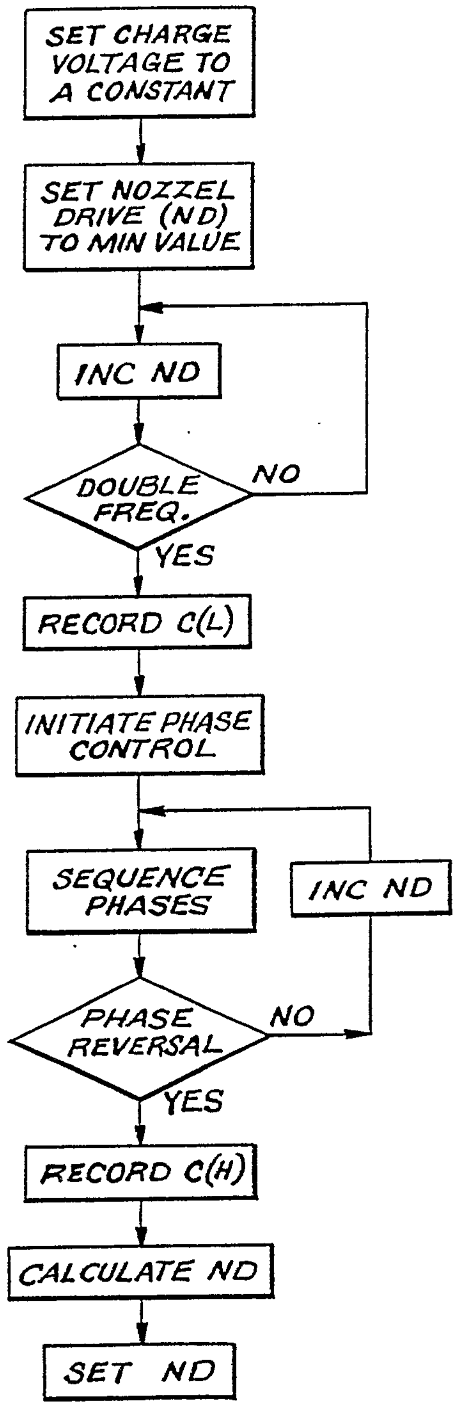

WITHIN CHARGE TUNNEL
PHASES
0=NO DETECT
1= DETECT
φ0 φ1 φ2 φ3
NOZZLE DRIVE VOLTS
80°F
10
12
14
16
S
A
0 0 1 1
1
SLOW SATELLITES
B
0 1 1 0
10
INTERMEDIATE SATELLITES C(L)
C
1 1 0 0
15
FAST SATELLITES
D
1 0 0 1
27
V(CALC)
E
0 0 1 1
33
FAST SATELLITES
F
0 1 1 0
42
FAST SATELLITES
G
1 1 0 0
48
DROP SEPARATION FOLD BACK C(H)
H
0 1 1 0
50
PHASING SEQUENCE REVERSED

FIG. 1

FIG. 2


SET CHARGE VOLTAGE TO A CONSTANT
SET NOZZEL DRIVE (ND) TO MIN VALUE
INC ND
DOUBLE FREQ.
NO
YES
RECORD C(L)
INITIATE PHASE CONTROL
SEQUENCE PHASES
INC ND
PHASE REVERSAL
NO
YES
RECORD C(H)
CALCULATE ND
SET ND

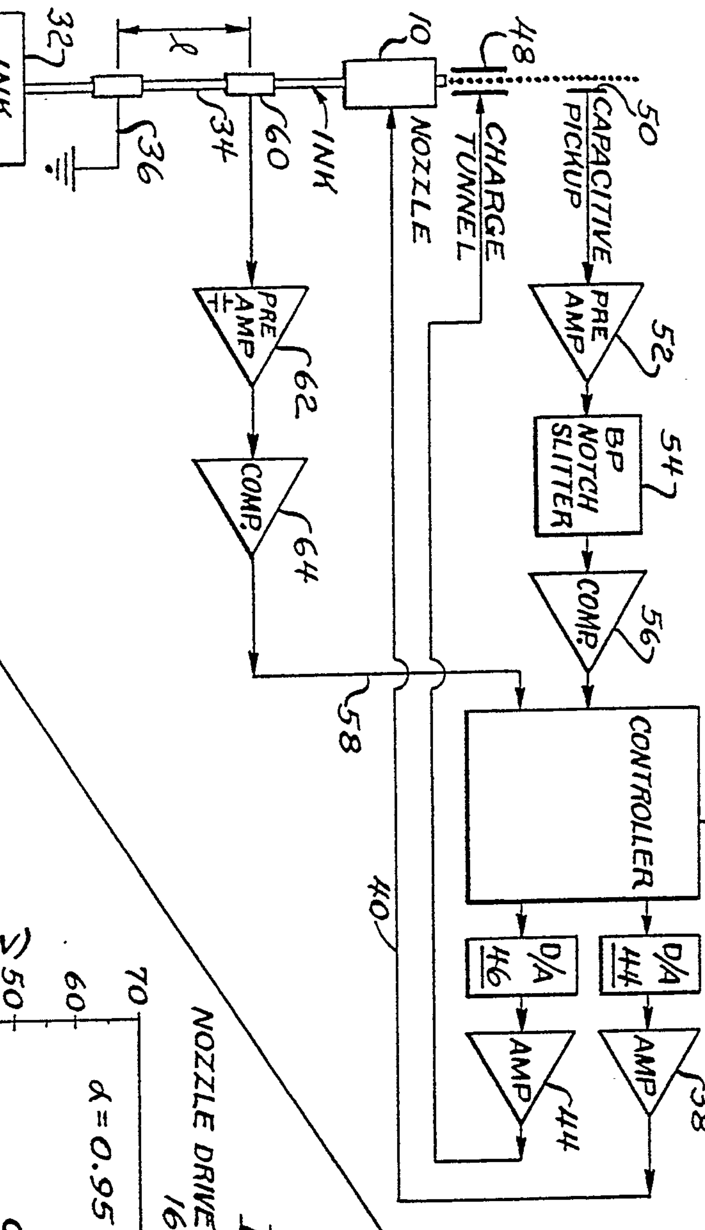


FIG. 3

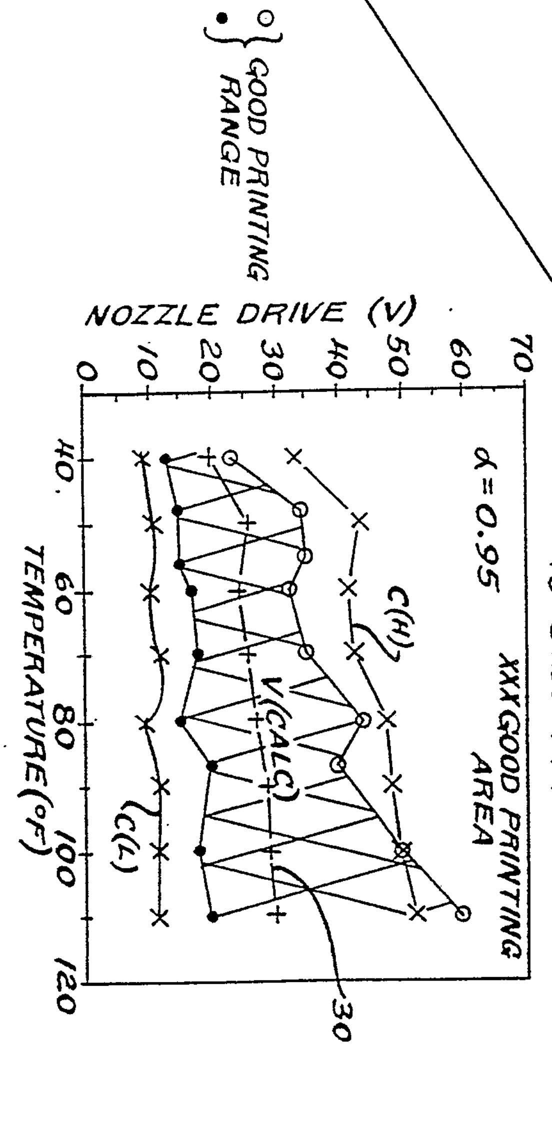


FIG. 4

NOZZLE DRIVE RANGE VS. TEMPERATURE 16-8200 INK

FIG. 5

INTERMEDIATE SATELLITE DETECTORS

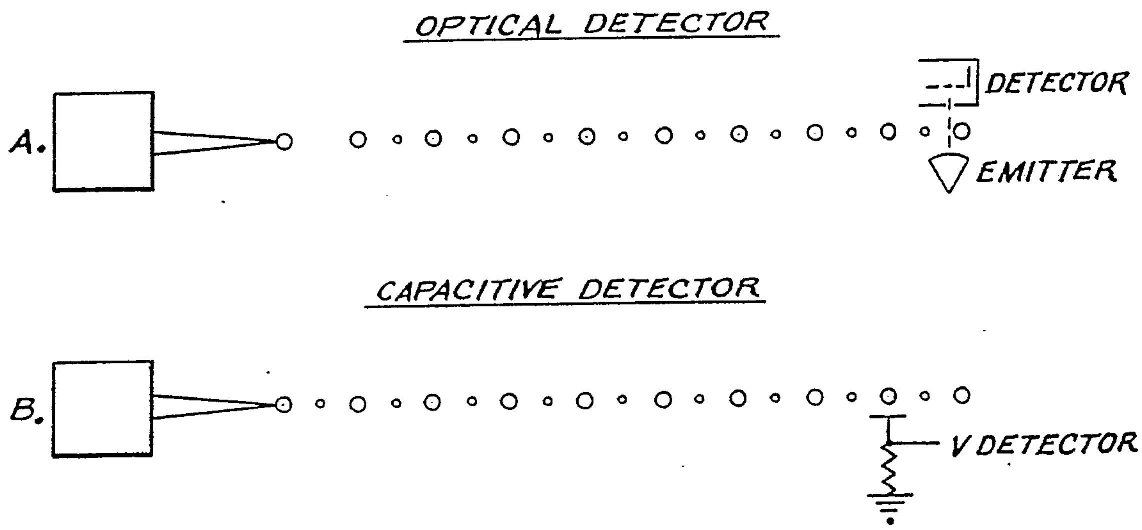
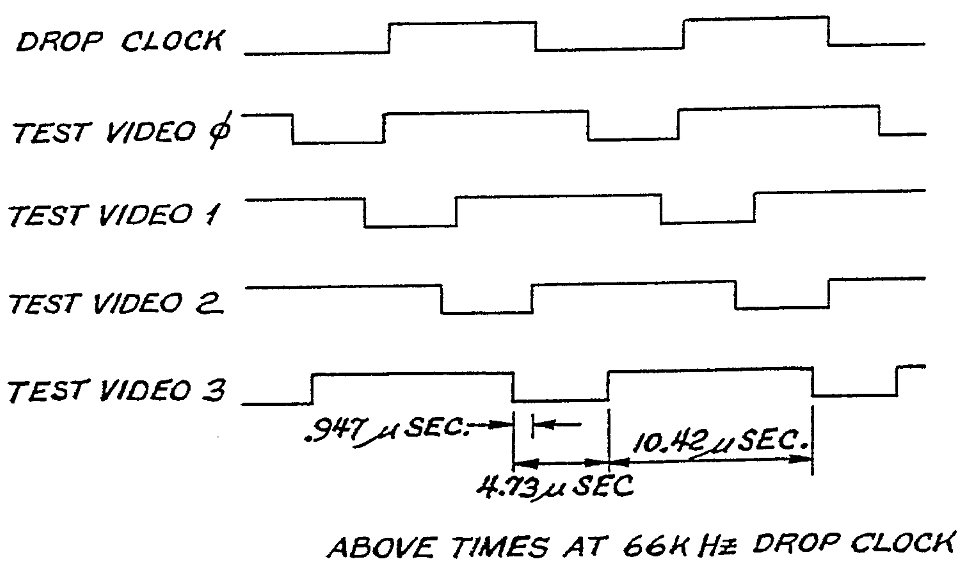


FIG. 6



European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 90303101.1

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl 5)
A	WO - A1 - 87/01 074 (EASTMAN KODAK COMP.) * Totality *	1,2,8, 10, 13-17	B 41 J 2/02 B 41 J 2/12 G 01 D 18/00
A	US - A - 4 638 326 (YAMADA) * Totality *	1,2,5, 6,8, 10,12, 13,15, 17	
D,A	EP - A1 - 0 287 373 (DOMINO PRINTING SCIENCES) * Totality *	1,2,8, 10,14, 16,17	
D,A	US - A - 4 638 325 (SCHNEIDER) * Totality *	1,2,8, 10,14, 16,17	

TECHNICAL FIELDS SEARCHED (Int Cl 5)

B 41 J
G 01 D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	02-07-1990	WITTMANN

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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