PATENT SPECIFICATION

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(72) Inventors LAWRENCE KUHN
ROBERT ANTHONY MYERS and
ROY LAWRENCE RUSSO

(54) INK JET RECORDING APPARATUS

(71) We, INTERNATIONAL BUSINESS MACHINES CORPORATION, a Corporation organized and existing under the laws of the State of New York in the United States of America, of Armonk, New York 10504, United States of America do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to ink jet recording apparatus.

The invention provides ink jet recording apparatus capable of recording marks on a record media at a multiplicity of locations at substantially the same time under the control of a supplied data word containing information as to the locations at which marks are to be made, said apparatus comprising a multiplicity of nozzles arranged in a planar array and from which a corresponding multiplicity of parallel jets of ink are caused to issue in use; means for introducing substantially synchronous perturbations into the ink jets so that the jets break-up into streams of equal sized, uniformly spaced ink droplets at charging locations each located at substantially the same distance from its associated nozzle; a multiplicity of charging electrodes for imparting charges to individual droplets, the electrodes being associated respectively with individual ink jets, being located at the charging locations, and being arranged in a planar array substantially parallel to the planar nozzle array; means for energising the electrodes in accordance with information derived from a current, supplied data word; and means for controlling the relative timing of energisation of the electrodes by the energisation means so that charges are applied to droplets which are incident on the record media at substantially the same time as distinct from droplets which arrive at the electrodes at substantially the same time.

In a preferred construction each stream of droplets comprises sequences of droplets, each sequence being uniquely associated with a marking location and comprising 3 K droplets where K is an integer corresponding to the number of droplets to mark a single location and the relative-timing-control-means comprise means for selecting the leading N droplets, the middle N droplets or the trailing N droplets of a sequence depending upon whether the timing is to early, synchronous, or late relative to a datum timing.

The preferred construction further comprises a data store providing *n* addressable locations at which timing words can be stored, each location comprising an information storage position for each nozzle at which position information can be stored indicating whether the droplet formed during the currency of that timing word is to be selected or not; means for addressing the timing words in a timed sequence during the currency of each data word; and means for masking the current data word with each of the timing words to generate a sequence of *n* sets of control signals for controlling energisation of the electrodes.

An ink jet printer embodying the invention will now be described by way of example with reference to the accompanying drawings, in which:—

Figure 1A is a fragmentary perspective view of parts of the printer,

Figure 1B is a similar fragmentary perspective view showing some nozzles, charging tunnel electrode structures and a control circuit chip,

Fig. 1C shows the manner in which the control circuit chip of Fig. 1C is bonded to the charging tunnel electrode substrate.

Fig. 2A shows the timing diagram for voltages associated with the system of Fig. 1A.

Fig. 2B is a schematic diagram of a portion of the mechanism of Fig. 1A for measuring the relative transit times of the various jets.

Fig. 3 shows an example of the transit times of ink drops for various jets having various delays D_n.

Fig. 4 shows a matrix of correction data for twelve correction times C_m during a data cycle versus the eight different ink jets of Fig. 3.

Fig. 5 is a flow chart which shows how to derive the transit time data of Fig. 3 and the matrix of Fig. 4 from the system.

Fig. 6 shows the timing chart and the contents of the data register, correction register, and output register for two examples of data values and using the correction matrix of Fig. 4.

Fig. 7 shows the control system for the printer and the connections of the registers.

Description of the Preferred Embodiment

Fig. 1A shows an ink jet printing system in which a head 9 with a vertical array of nozzles 12 sweeps back and forth across a page 24 of paper imprinting data thereon selectively. Depending upon requirements, the nozzle array can include from 2 to 5,000 nozzles, printing many lines or a page at a time, in the extreme.

An ink manifold 10 is provided to which ink from a reservoir (not shown) is supplied through a supply tube 11. The ink is an electrically conductive liquid. The manifold 10 has the ink supplied under pressure so that the ink flows from nozzles 12 in a nozzle plate 14 as a plurality of liquid streams 15.

The manifold 10 is subjected to vibrations from suitable vibrating means 16 such as a piezoelectric transducer, for example. The vibrations created by the vibrating means 16 cause each of the streams 15 to be broken up into a plurality of substantially uniformly spaced droplets 18.

A spacer 19 disposes a charging head 20, which includes a substrate 21 formed of a suitable insulating material in spaced relation to the nozzle plate 14 so that each of a plurality of passageways 22 formed therein has the droplets 18 from the stream 15 break up within the passageway 22. The substrate 21 has a plated material 23 shown in Fig. 1B formed in a selected portion therein in surrounding relation to each of the passageways.

Therefore, when a voltage is supplied to the plated material 23, which functions as a charging electrode, the droplet 118, which is breaking off from the stream 15 but still connected thereto and disposed within the passageway 22, is charged. Charging of the droplet 118 by electrode 23 being activated results in droplet 118 not being utilized to print on a recording medium such as a paper 24, which is moving in the vertical direction indicated by arrow 25.

If the droplet 118 is charged by electrode 23, droplet 118 will deflect into gutter 26, which has a tube 27 returning the ink droplets 118 from gutter 26 to the reservoir to which the manifold 10 is connected through the supply tube 11. The charged droplet 118 is deflected into gutter 26 by a deflector 28.

The deflector 28 includes a pair of parallel electrodes 29 and 30 with a deflection voltage V_0 supplied to the electrode 29 and the electrode 30 being grounded and having the gutter 26 connected thereto. Accordingly, all of the charged droplets 18 are deflected by deflector 28 towards gutter 26. Thus, the print pattern on the paper 24 is determined by the droplets 18, which have not been charged within the passageways 22.

Each of the electrodes 23 is connected to a plated lead 32 on front surface 33 of the substrate 21. Each of the leads 32 is connected to chip 34 carrying a plurality of circuits which also are formed in the front surface 33 of the substrate 21. Each of the circuits preferably is formed by a plurality of FETs. Data, timing, and correction information is supplied to chip 34 on cable 37. Such an arrangement is illustrated in detail in Fig. 1B where head 9 includes nozzle plate 14 spaced from an insulating charge tunnel substrate 21 by spacers 19. Chip 34 is bonded to the charge tunnel substrate 21 with the active side of the chip 34 facing the charge tunnel substrate.

A plurality of holes or slots 38, 39 and 40 are formed in substrate 21. These slots are plated on the interiors and exteriors thereof with a conductive plating, with conductive strips 32 being plated in a like manner for forming charge electrode conductors, which are in contact with signal lines from chip 34.

Fig. 1C illustrates in more detail how the chip 34 is bonded to the charge tunnel substrate 21. A charge electrode conductor 32 is bonded to a signal line 41 by a solder connection 43. The solder 43 is reflowed at each position where it is desired to connect a signal line from the drive chip 34 to a charge electrode conductor on the insulating charge tunnel substrate 21. Layers 42 are composed of glass. The conductors and solder reflow joints may be passivated.

Electronic Compensation

The key to implementing an electronic scheme for correcting transit time errors lies in the obvious fact that the faster drops get to the paper sooner. Hence, if the information signal that permits a drop to print (recall the system prints with uncharged drops) is delayed a proper amount for the fast streams, then all drops which are supposed to strike the paper together can be made to do so (subject to a minimum error corresponding to the distance the paper moves during a single drop cycle, i.e., the time between successive drops).

This system measures the transit time of each stream on a periodic basis, processes the data so that the delay required for each charge electrode is available, and then uses the delay information to control the time at which an information signal is applied to each charge electrode.

Fig. 2A shows a data signal which is generated by a data clock once at the beginning of every data period, which lasts M units of time, and, in Fig. 2A, M=12 as shown by the V_M voltage which has a period equal in time to the period between generation of drops in Fig. 2B. When it is desired to calibrate the head 9, it is driven all the way to the left as shown in plan view in Fig. 2B and aimed at electrode 51 in target 50. The deflection field set up by voltage V is turned off. Sample drops from each of the jets are charged one at a time by application of voltage V_n ($V_1, V_2, V_3, \ldots, V_N$) as they pass by corresponding charging electrodes 23. The transit times T_n shown in Fig. 2A are determined by counting the number of V_M pulses that occur between application of the charging voltage V_n and detection of the next V_{sense} pulse by the sensor 50. Other means of measuring transit time are well known to those skilled in the art. The accuracy required is to time the flight to the nearest drop formation period.

The maximum correction that can be achieved in this embodiment is for a transit time error equal to the number of drop formation periods, M, during one data period minus the number of print drops for each picture element which is denoted by the letter K. Furthermore, the velocity increments will be of the order of the ratio of the wavelength to the flying distance, which is of the order of 1%. Of course, the process is repeated for each stream 12 in turn, and the transit time information is stored. Assuming a transit time can be measured in 1 millisecond, the most time that would be required (e.g., for a 1000 nozzle array) would be about 1 second. The frequency with which this measurement will be made will be a function of the design of the machine.

Processing

In order to provide correction of errors caused by velocity, the correction information is placed into a special format in Fig. 4. First, assume that the transit time is measured in units of the drop cycle (of the order of 10 microseconds). The longest time count Tmax is detected for the slowest stream, and the difference $T\max - T_n$ is taken between the transit time of the slowest stream and each other stream (assuming, for definiteness, 3-bit accuracy). Then, for all streams for which this transit time difference is 0, 0, 0, the printing signals are placed on the charge electrodes without delay. All those streams which differ by one unit require a delay of one drop cycle so that the information bit is applied to a drop which breaks off one cycle later.

The data is ordered as follows. Let N be the number of nozzles. Let M be the number of drop cycles for which it is intended to correct the transit time (e.g., eight or sixteen drop cycles; three or four bits, in other words). Place in memory, or other suitable storage, M words, each word being N bits, numbered 1, 2, . . . N. For each nozzle n_0 requiring zero delay, place a "1" in bit n_0 of the words 1,2, . . . , K. For each nozzle n_1 requiring a delay of one drop cycle, place a "1" in bit n_1 of words 2, 3, . . . , 1+K. In general, for each nozzle n_i requiring a delay of i drop cycles, place a "1" in bit n_i of words i+1, . . . , i+K. After all N nozzles have been treated, place a "0" in all bit locations where A "1" has not been placed. Thus, an M×N bit correction matrix is formed carrying all the required delay information.

Referring to Fig. 3, an example of transit times T_n for an eight-jet head is shown with a Tmax (maximum transit time) of 103 drop cycles for jet 1 and a Tmin (minimum transit time) of 97 drop cycles for jet 3. The difference between Tmax and Tmin is Dmax (maximum difference in transit times). Here, Dmax=103–97=6 drop cycles. The difference between Tmax and any given transit time T_n for jet n=0, 1, 2 . . . 8 is Dn (difference in transit time from Tmax for nozzle n), D_n=Tmax–T_n.

In Fig. 4 a matrix is shown which is derived by using the algorithm or procedure defined in Fig. 5 to calculate correction words C_n for introduction into a correction delay register 60 shown in Fig. 7. Intuitively, one can see that since jet 1 is the slowest, having the maximum transit time, that its data printing signals should be first among those of the eight jets in Fig. 3. Now, in addition, it has been determined that in order for a data unit to print a large enough spot to be seen, K consecutive drop periods should be printed. For a particular desirable machine embodiment the number K should be 4. Thus, in Fig. 4, the correction bit C_0 for jet 1 is 1, since C_0 will be used to gate out the data imparting signal to the output register 61 in Fig. 7, which will turn on jet 1 at the very beginning of a data cycle, after the zero pulse of clock 3 in Fig. 6. In addition, the jet 1 bit in words C_1, C_2, and C_3 are all 1's too in order to continue to print any bit for K=4 drop periods, as explained above.

Now one can refer to Fig. 5 and follow through the steps defined there with respect to Figs. 3 and 4 and see how they correlate.

Fig. 6 shows how the correction matrix of Fig. 4 is applied to a specific pair of values in a data register 62 in Fig. 7 with the correction register words C_0—C_{11} going from the controller 81 to the correction register 60 for each data word.

The first word in the data register is binary 01110101. For the first bit position then, there will be no drop produced as reflected below in Fig. 6 for jet position 1 of the output register. The values in the correction register are not effective to produce an output, since data and correction register values at any given clock 3 time must both be 1's to produce a 1 in the corresponding output register.

The second jet data register values is a 1, but since bit 2 of C_0, C_1 . . .C_4=0, the output register for jet 2 remains zero until drop time 5 when C_5=1 as do C_6, C_7 and C_8. Thus, the output register value for jet 2 is a 1 for times 5, 6, 7, and 8.

The example for the second data word starts off with a 1 for jet 1, so since jet 1 also has a 1 value for time 0, i.e., C_0=1, the first output data bit is a 1.

Referring to Fig. 7, in the jet 1 position 65 of data register 62, if at clock 1 time a "1" is applied to register position 65, then line R_1 is up. When line 67, B_1, is up because the value in the jet 1 latch 66 of correction register 60 is a "1", then AND 68 is turned on to activate flip-flop 70 to the "1" condition to deactivate the ink charging electrode 23 for jet 1, 51 so as to print a spot. K drop times later, line 67 will go down and line 83, $\bar{B}_1$ will go up. When clock pulse 3 occurs, AND 68 turns off and AND 71 turns on to reset latch 70. The purpose of AND 200 is to reset latch 70 when the data bit changes from a "1" to a "0". Operation of the remainder of the elements of the input register 62, correction register 60 and output register 61 operate in like manner as will be obvious to those skilled in the art of digital circuits as applied to ink jet technology.

Included on chip 34 are registers 60, 61, and 62. A clock generator in controller 81 provides clock 1, 2, and 3 signals which coordinate the operations of chip 34. Processor 63 sends input data words to controller 81 which in turn sends the data, the correction data an the clock signals to chip 34. The details of processor 63 and controller 81 are well known to those skilled in the art of data processing.

The operation of the delay logic may best be understood with the aid of Fig. 7. It is assumed that a controller 81 presents the printer with a coded data stream representing the material to be printed. Cable 77 is fed the N-bit correction word that was described in the previous section and contains the information as to when each charge electrode is to be presented with its data bit.

Note that two registers 60 and 62 are indicated as being N-bit long registers. These registers have been described as being fed data in parallel. They may be fed serially, in which case, the maximum length of these registers is determined by the requirement that they may be filled in a time shorter than a drop cycle. Thus, each register may be divided into two or more segments, with the controller 81 responsible for arranging the data so that it is placed on the correct input lines. The clock signals would be changed appropriately to handle serial shifting. Due to pin limitations and modularity consideration more than to anything else, the number of nozzles that would be controlled by a single chip is probably of the order of 10—100, in which case it is unlikely that the registers would have to be divided into more than at most a few sections.

In printer operation, a new N-bit data word is provided once every M drop cycles. The function of the correction register 60 and the AND gates is to delay a bit which is destined for a charge electrode 23 until such time as the stream's transit time dictates. In a print head, applying a signal to the charge electrode 23 is equivalent to setting the appropriate flip-flop in the output register 61. In the print head, a flip-flop can be coupled to another higher voltage driver.

The logic functions as follows. At the start of a data cycle, assume the output register 61 is still set with data from the previous cycle. The data register 62 is then loaded with the new data information and, at the same time, the correction register 60 is loaded with the first N-bit correction word. Then there is a "1" in every location of register 60 for which the corresponding nozzles require zero delay. The data bits go to the output register 61 by ANDing each bit of each data bit in register 62 with its associated bit in register 60. If there is a "1" in both position *i* of register 62 and position *i* of register 60, then position *i* of register 61 is set to "print". If there is a "0" in position *i* of register 60 or position *i* of register 62, then position *i* of register 61 will be set "not to print".

One drop cycle later, the next N-bit delay word is loaded into the delay register, and the process is repeated. It is repeated until all the allowed delays have been cycled, at which time a new data word is at hand.

A preliminary sizing of the amount of logic required for the operations described above (i.e., those functions represented on the schematic) is a maximum of 20 gates per nozzle. (It is possible that this could be reduced by a factor of as much as five by using a custom shift register element design). Thus, without any custom design, it appears that a 20-nozzle delay chip would have of the order of 400 gates. Note that the problem is made simpler by the very regular and simple functions that the chip is to perform.

The number of gates, pins, etc. is not dependent on whether the correction is to three or four-bit precision. The influence of that factor is the speed with which it is necessary to load the shift registers. In fact, the same basic design could be used for either three or four-bit precision, with the only likely change required being dividing the shift registers.

Break-off Uniformity

Velocity uniformity is usually a severe limit on printer performance. The errors that might be introduced by non-uniform drop break-off length should be less. For example, a stream which breaks off one full wavelength out of phase with the other streams will, in effect, have a data signal which is displaced by only one drop cycle. As shown above, this is the order of the residual error for which this scheme cannot correct.

Break-off uniform to within a wavelength is achievable now for rather long arrays. On the other hand, a stream which breaks off ten wavelengths out of phase with the other steams will almost certainly break off outside the charging tunnel and, hence, will correspond to a "fail" state of that nozzle. Between those two extremes, however, this correction logic works to correct break-off nonuniformities as well as velocity nonuniformities. In fact, it cannot discriminate between the two sources of placement error.

Although one limit on using long nozzle arrays is, indeed, obtaining uniform holes, another problem is that of providing uniform excitation to long arrays. The scheme described here, or one that is equivalent, is required in order to print with high quality using long arrays, if other factors limit the uniformity of acoustic excitation giving rise to non-uniform drop breakoff length.

Numerical Example

data rate *f* data =9.6 KHz (τ data=104.17 μs)

$$M=\frac{\text{f drop}}{\text{f data}}=12$$

drop rate *f* drop =115.2 KHz (τ drop=8.68 μs)
jet diam. *d* jet =25.4 μm
drop separation Λ =139.7 μm
jet velocity v_j $=139.7\times10^{-6}$ m$\times115.2\times10^{3}$ sec^{-1}=16.09 m/sec
nozze to paper dist. =1.25 cm

Suppose the correct volume of ink per resolvable or addressable spot requires K=4 drops at a resolution of v=8 pel/mm ($R=v^{-1}$=.125 mm). The head is moved at a velocity $v_h = R \times f$ data=1.2 m/sec. Resolution (R) is defined as the closest center-to-center spacing of independent pels.

The invention is most useful for long nozzle arrays, for instance $N \sim 50$—1000. However, it can be used for short arrays as in this example where N=8, arbitrarily.

The drop misregistration on the paper is given, by $\Delta X_p = v_h \times (T\max - T\min)$ where Tmax and Tmin are the maximum and minimum transit times among the jets from the point of drop formation to the paper. These variations in transit time result from both velocity and break-off length variations. This can be expressed more conveniently as

$$\Delta X_p \simeq R\ (T\max - T\min)/M = R\ D\max/M$$

where R is one resolution element and the T's are the number of drops formed during transit time. For this example, Tmax=103 and Tmin=97, giving Dmax=6. Thus, without compensation, the print error is 1/2 of a picture element. With compensation, the error is reduced by a factor 6 to R/M, giving an error less than 1/12 of a picture element.

It is common to express the delay or transit time variation in terms of the velocity variation. In this case $(V\max - V\min)/V\text{avg} \simeq 8.4\%$, assuming all error is from velocity and break-off variation is negligible. Using the invention, performance is comparable to what would be achieved with no correction and $\Delta V/V \simeq 1.4\%$.

Restated in another form, since the head parameters are chosen such that the head moves a distance corresponding to one picture element (R) during M drop cycles, the misregistration between the slowest and the fastest jet must be

$$\Delta X_p \simeq \frac{R}{M} \times D\max$$

without compensation. With compensation, it is reduced to R/M.

WHAT WE CLAIM IS:—

1. Ink jet recording apparatus capable of recording marks on a record media at a multiplicity of locations at substantially the same time under the control of a supplied data word containing information as to the locations at which marks are to be made, said apparatus comprising a multiplicity of nozzles arranged in a planar array and from which a corresponding multiplicity of parallel jets of ink are caused to issue in use; means for introducing substantially synchronous perturbations into the ink jets so that the jets break-up into streams of equal sized, uniformly spaced ink droplets at charging locations each located at substantially the same distance from its associated nozzle; a multiplicity of charging electrodes for imparting charges to individual droplets, the electrodes being associated respectively with individual ink jets, being located at the charging locations, and being arranged in a planar array substantially parallel to the planar nozzle array; means for energising the electrodes in accordance with information derived from a current, supplied data word; and means for controlling the relative timing of energisation of the electrodes by the energisation means so that charges are applied to droplets which are incident on the record media at substantially the same time as distinct from droplets which arrive at the electrodes at substantially the same time.

2. Apparatus as claimed in claim 1, in which each stream of droplets comprises sequences of droplets, each sequence being uniquely associated with a marking location and comprising 3 K droplets where K is an integer corresponding to the number of droplets to mark a single location, and in which the relative-timing-control-means comprise means for selecting the leading N droplets, the middle N droplets or the trailing N droplets of a sequence depending upon whether the timing is to early, synchronous, or late relative to a datum timing.

3. Apparatus as claimed in claim 1, in which each supplied data word is current for a recording interval and during each such interval each jet provides a group of *n* droplets, in which the energising means are operable to select a sub-group of *m* droplets from each group of *n* droplets corresponding to a location at which a mark is to be recorded, and in which the timing means are operable to select the positions of the sub-groups within the respective groups of *n* droplets so that corresponding droplets of the sub-group are incident on the record media at substantially the same time.

4. Apparatus as claimed in claim 3, further comprising a data store providing *n*

addressable locations at which timing words can be stored, each location comprising an information storage position for each nozzle at which position information can be stored indicating whether the droplet formed during the currency of that timing word is to be selected or not; means for addressing the timing words in a timed sequence during the currency of each data word; and means for masking the current data word with each of the timing words to generate a sequence of n sets of control signals for controlling energisation of the electrodes.

5. Apparatus as claimed in claim 4, in which the masking means comprise a data register in which the current data word is stored; a timing register in which the n timing words are successively entered while a single data word is stored in the data register; and a logical network for combining the outputs of corresponding register positions and for generating the aforesaid sets of control signals.

6. Apparatus as claimed in any one of claims 1 to 5, further comprising means for producing a time signal representing measure of the droplet flight time, in each stream of droplets, from the charge electrode to an end position at or near the record media position.

7. Apparatus as claimed in claim 6, in which each flight time is measured in terms of the number of droplet-formation-intervals elapsing during transit of a droplet from the electrode to the end position, an approximation being made to the nearest whole number of droplet-formation-intervals.

8. Apparatus as claimed in claim 6 or 7, in combination with data processing means to which the time signals are supplied and which are operable to process the time signals to provide charge timing signals for the energisation-controlling-means.

9. Apparatus as claimed in claim 8, in which the processing means are operable to determine the longest droplet flight time (T_{max}), to calculate the difference (D_n) between the actual flight time (T_n) of each other stream and the maximum flight time, $D_n=T_{max}-T_n$, and to produce therefrom a sequence of timing words determining which droplets can be used, under the control of a current data word, to mark the record media.

10. Apparatus as claimed in claims 4 and 8, in which n timing words are produced, one for each droplet of a sequence of n droplets and in which each timing word comprises an information storage position for each nozzle whereby each droplet issuing from each nozzle is uniquely associated with a storage position on one of the timing words.

11. Ink jet printing apparatus substantially as hereinbefore described with reference to, and illustrated in the accompanying drawings.

ALAN J. LEWIS,
Chartered Patent Agent,
Agent for the Applicants.

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FIG. 1A

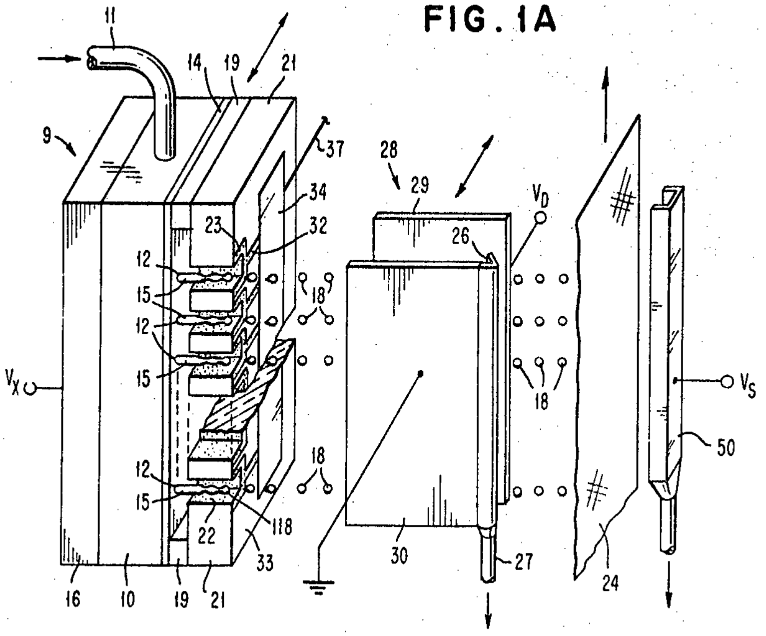


FIG. 1B

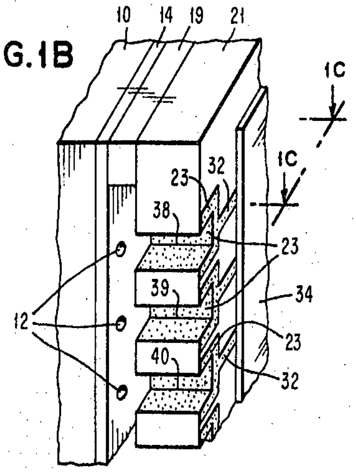


FIG. 1C

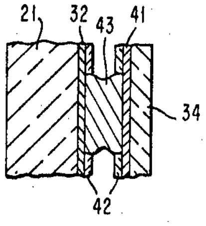
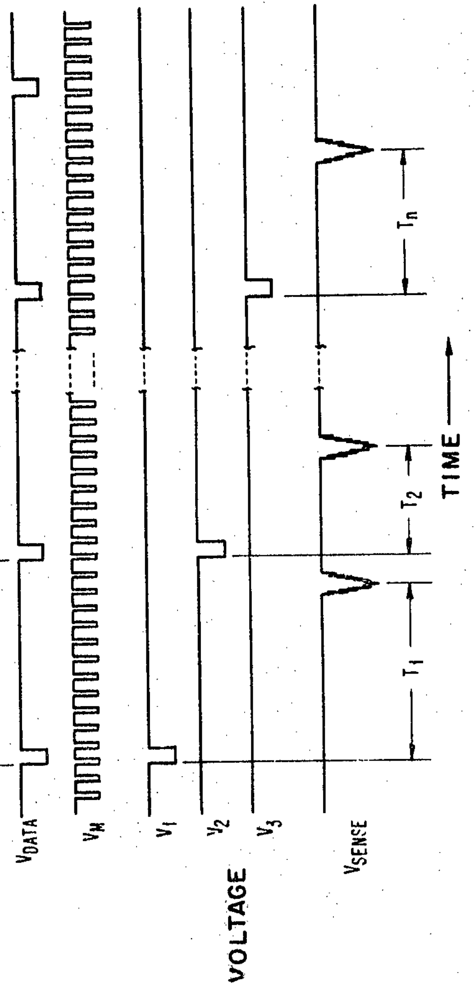


FIG. 2A


V_DATA
V_M
V_1
V_2
V_3
V_SENSE
VOLTAGE
T
T_1
T_2
T_n
TIME

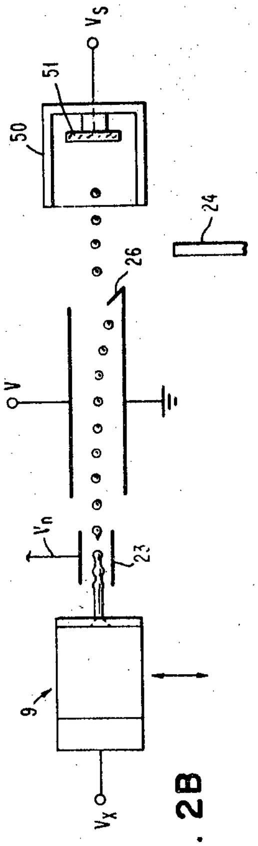

V_X
9
V_n
23
V
26
24
50
51
V_S

FIG. 2B

FIG. 3

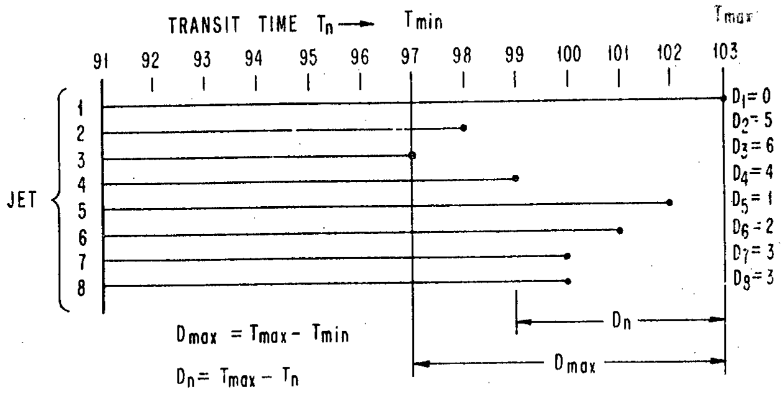


FIG. 4

N = 8, M = 12

JET	C_{11}	C_{10}	C_9	C_8	C_7	C_6	C_5	C_4	C_3	C_2	C_1	C_0
1	0	0	0	0	0	0	0	0	1	1	1	1
2	0	0	0	1	1	1	1	0	0	0	0	0
3	0	0	1	1	1	1	0	0	0	0	0	0
4	0	0	0	0	1	1	1	1	0	0	0	0
5	0	0	0	0	0	0	0	1	1	1	1	0
6	0	0	0	0	0	0	1	1	1	1	0	0
7	0	0	0	0	0	1	1	1	1	0	0	0
8	0	0	0	0	0	1	1	1	1	0	0	0

FIG. 5

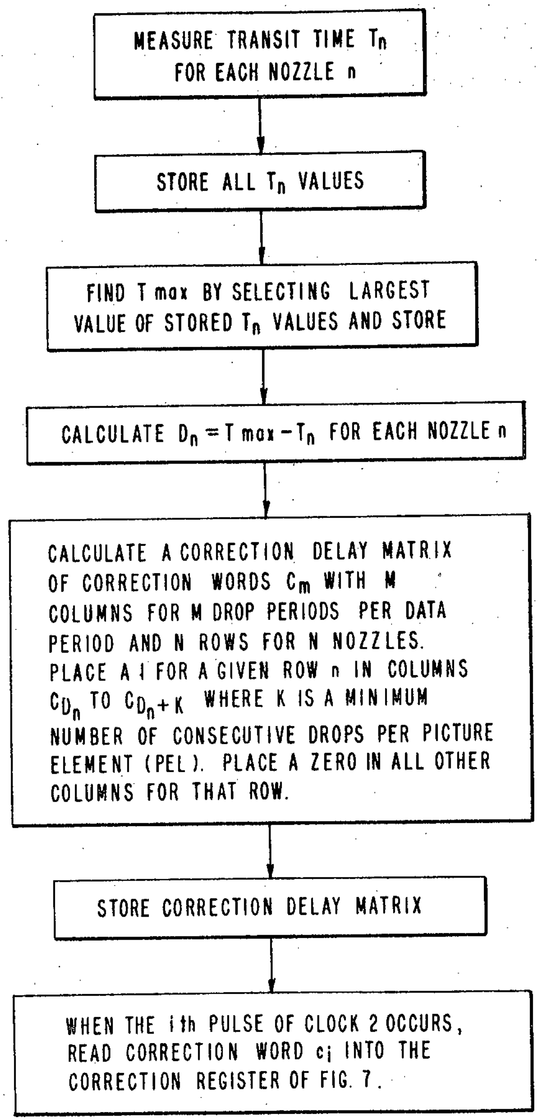
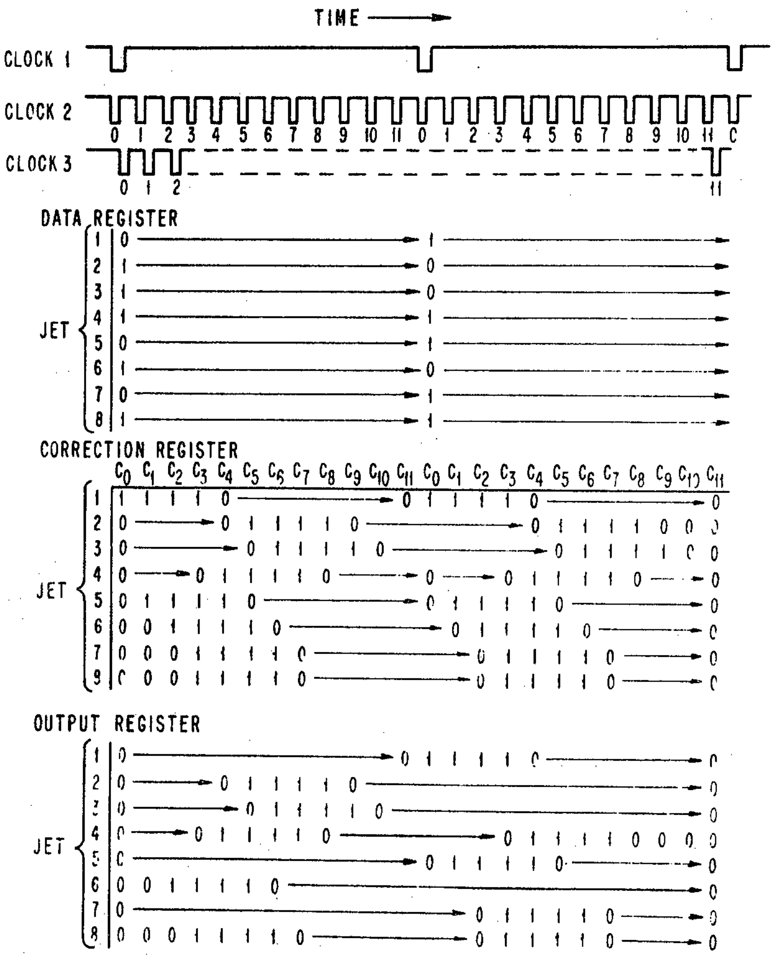

MEASURE TRANSIT TIME T_n FOR EACH NOZZLE n
STORE ALL T_n VALUES
FIND T max BY SELECTING LARGEST VALUE OF STORED T_n VALUES AND STORE
CALCULATE $D_n = T\,max - T_n$ FOR EACH NOZZLE n
CALCULATE A CORRECTION DELAY MATRIX OF CORRECTION WORDS C_m WITH M COLUMNS FOR M DROP PERIODS PER DATA PERIOD AND N ROWS FOR N NOZZLES. PLACE A 1 FOR A GIVEN ROW n IN COLUMNS C_{D_n} TO C_{D_n+K} WHERE K IS A MINIMUM NUMBER OF CONSECUTIVE DROPS PER PICTURE ELEMENT (PEL). PLACE A ZERO IN ALL OTHER COLUMNS FOR THAT ROW.
STORE CORRECTION DELAY MATRIX
WHEN THE i th PULSE OF CLOCK 2 OCCURS, READ CORRECTION WORD c_i INTO THE CORRECTION REGISTER OF FIG. 7.

FIG. 6


TIME
CLOCK 1
CLOCK 2
0 1 2 3 4 5 6 7 8 9 10 11 0 1 2 3 4 5 6 7 8 9 10 11 C
CLOCK 3
0 1 2
11
DATA REGISTER
JET
1 2 3 4 5 6 7 8
CORRECTION REGISTER
C0 C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11 C0 C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11
JET
OUTPUT REGISTER
JET

1586590 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 6

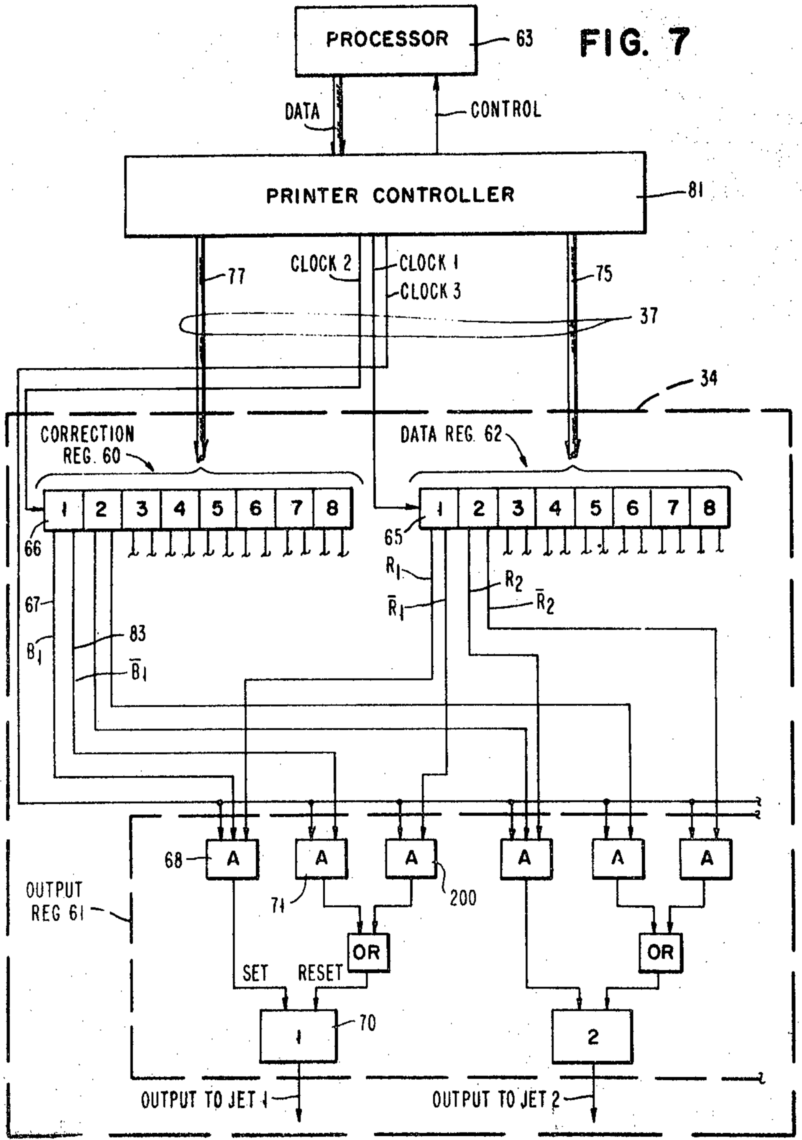


FIG. 7