(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 947 327 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
06.10.1999 Bulletin 1999/40

(51) Int. Cl.[6]: **B41J 2/14**, B41J 2/045

(21) Application number: **99106686.1**

(22) Date of filing: **01.04.1999**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **02.04.1998 JP 8996998**

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(54) Ink-jet print head, driving method thereof and ink-jet printer using the same

(57) In an ink-jet print head, a plurality of sets of pressure chambers (6a, b, c) and supply paths (7a, b, c) are provided to be connected to one another in series between a nozzle (5) and an ink pool (8). Piezoelectric transducers (1a, b, c) are arranged to be opposite to the respective pressure chambers. A driving circuit therefor sequentially applies voltage waveforms to the piezoelectric transducers starting from a piezoelectric transducer provided in the first pressure chamber connected to the ink pool to piezoelectric transducers of the nozzle-side adjacent pressure chambers. At this moment, the piezoelectric transducers provided in the nozzle-side pressure chambers are applied with voltage waveforms delayed in phase by 1/2 of natural periods of pressure waves in the pressure chambers.

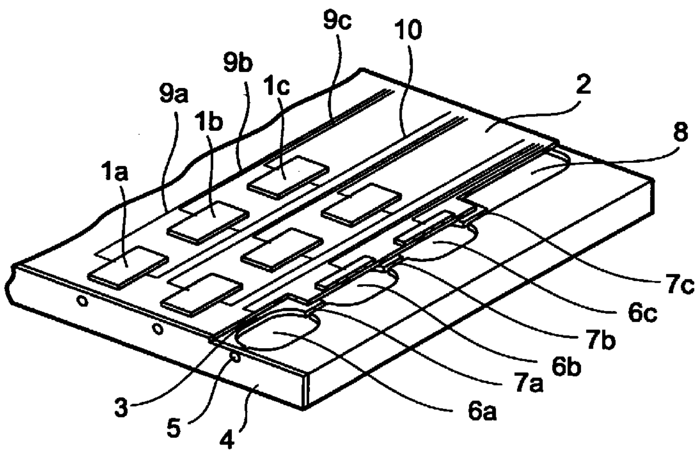

FIG.1

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Description

[0001] The present invention relates to an ink-jet print head, a driving method thereof and an ink-jet printer using the same. The present invention relates to, in particular, a drop-on-demand type ink-jet print head for discharging ink using piezoelectric transducers, a driving method thereof and an inkjet printer using the same.

[0002] In recent years, it has become prevalent to deal with multi-gradation images such as picture images even on a personal computer. Accordingly, high-quality gradation printing is required of an ink-jet type printer serving as a device outputting these images.

[0003] According to a conventional ink-jet print head of this type, the displacement amount of a piezoelectric transducer in a pressure chamber provided per nozzle is changed, the sizes of ink droplets discharged from the nozzle are made variable to thereby output multi-gradation images at high resolution.

[0004] However, there is a limit to the number of stages in which the sizes of ink droplets discharged at a time can be stably set. For instance, the dimensions of a pressure chamber are set small so as to allow stable discharge of small ink droplets. In order to discharge large ink droplets, meanwhile, it is also necessary to provide a piezoelectric transducer of large displacement amount to discharge large ink droplets. A normal single piezoelectric transducer cannot exhibits sufficient displacement amount. Furthermore, if a multi-layered piezoelectric transducer which can exhibit larger displacement amount than a single-layered piezoelectric transducer is to be used, it is necessary to increase the number of layers, which pushes up the cost. Also, it is difficult to output sufficiently high-quality multi-gradation images in a stable manner.

[0005] To solve the problems, there has been proposed a method of overstriking ink droplets on a dot a plurality of times using a print head for discharging small ink droplets, and controlling the overstrike frequency to thereby make gradation control.

[0006] With the method, it is possible to output sufficiently high-quality multi-gradation images in a stable manner. Nevertheless, the fact that ink is discharged on one dot a plurality of times causes the reduction of print speed.

[0007] There is also proposed a print method of preparing a low-density ink print head and a high-density ink print head individually, printing dots of predetermined density or less using the low-density ink print head and printing dots of predetermined density or more using the high-density ink print head.

[0008] Since this method requires preparing two different heads, i.e., the low-density ink print head and the high-density ink print head, the production cost increases accordingly.

[0009] There is yet another method disclosed by Japanese Unexamined Patent Application Publication No. 8-309971.

[0010] FIG. 13 is a block diagram of ink channels of the ink jet head disclosed therein.

[0011] In the example shown in FIG. 13, each communication hole 51 communicating with a nozzle 52 is tapered and becomes gradually small toward the direction of the nozzle 52. The hole 51 is provided with two pressure chambers 53 opposite to each other or offset each other in opposite directions. Side walls constituting the pressure chambers 53 are coupled to the communication holes while they form spirals in the same rotation direction in the vicinity of the holes 51.

[0012] If ink flows are simultaneously generated from the pressure chambers 53 communicating with the same communication hole 51 by the piezoelectric transducers, respectively, then the flows applied with rotation by the side walls turn into eddy flows and run into the communication hole 51. The flows are superimposed to thereby discharge large ink droplets from the nozzle 52. The ink droplet volume discharged from the nozzle is changed by selecting and driving one of or both of the two piezoelectric transducers installed on the two pressure chambers communicating with the single communication hole.

[0013] According to the conventional ink-jet head shown in FIG. 13, however, ink is discharged at right angle with the flow direction of ink generated in the pressure chamber and pressure chambers are coupled to each other through large openings, respectively. Due to this, it is difficult to efficiently make use of the energy applied onto the piezoelectric transducers for purposes of discharging ink.

[0014] Moreover, the side walls of the pressure chambers and the communication holes communicating therewith have complicated, three-dimensional configurations, which configurations make manufacturing process difficult and may cause cost increase.

[0015] It is, therefore, an object of the present invention to provide an ink-jet print head which can be easily manufactured and capable of multistage-varying ink droplets discharged from a nozzle without causing a reduction in print speed and without using an expensive layered piezoelectric transducer having great output changes.

[0016] An ink-jet print head according to the present invention includes a plurality of pressure chamber rows formed by connecting a plurality of pressure chambers in series through a supply path having a smaller channel area than the pressure chambers; a plurality of piezoelectric transducers provided in the pressure chambers, respectively and applied with voltage waveforms independently of one another; an ink pool communicating with a pressure chamber located on one end of each of the pressure chamber rows; and a plurality of nozzles each communicating with a pressure chamber located on the other end of the pressure chamber row.

[0017] In addition, an ink-jet printer according to the present invention includes the above-stated print head; a voltage applied device selection unit for selecting piezoelectric transducers applied with voltage wave forms based on ink droplets discharged from the respective nozzles for every pressure chamber row; and a plurality of voltage waveform application units for sequentially applying voltage waveforms to the piezoelectric transducers selected by the voltage applied device selection unit at voltage wave form application timing, at which voltage waveforms are sequentially applied to piezoelectric transducers of the first pressure chamber to the second pressure chamber for every pressure chamber row, the timing delayed in phase by 1/2 of natural periods of pressure waves in pressure chambers with respect to pressure chambers connected to one another on a ink pool side.

[0018] According to the present invention, pressure chambers are connected, in series, to one another between the nozzle and the ink pool and provided With piezoelectric transducers, respectively. The piezoelectrc transducers are sequentially and selectively driven with phase differences by 1/2 of natural periods of pressure waves in the respective pressure chambers given. By doing so, it is possible to discharge ink from the nozzle at high pressure resulting from combined pressure of the respective piezoelectric transducers if all of the piezoelectric transducers are driven. On the other hand, it is possible to discharge ink from the nozzle at low pressure if only one of the transducers is driven. Thus, the sizes of ink droplets discharged from the nozzle at a time can be varied in a plurality of stages.

[0019] Further, in another ink-jet print head according to the present invention, the pressure chamber rows include pressure chambers having different pressure wave natural periods of the pressure chambers.

[0020] Moreover, another ink-jet printer according to the present invention includes the above-stated another ink-jet print head; a voltage applied device selection unit for selecting piezoelectric transducers applied with voltage waveforms and maximum voltages of the voltage waveforms applied to the piezoelectric transducers; and a plurality of voltage waveform application units for generating voltage wave forms having maximum voltages for the piezoelectric transducers selected by the voltage applied device selection unit and sequentially applying the voltage waveforms to the selected piezoelectric transducers at voltage waveform application timing, at which voltage waveforms are sequentially applied to piezoelectric transducers of the pressure chamber connected to the ink pool to the pressure chamber connected to the nozzle for every pressure chamber row, the timing delayed in phase by 1/2 of pressure wave natural periods of pressure chambers with respect to pressure chambers connected to one another on a ink pool side.

[0021] According to the present invention, piezoelectric transducers applied with voltage waveforms are selected, voltage waveforms having the selected maximum voltages are generated for the selected piezoelectric transducers and the generated voltage waveforms are applied to the selected transducers. By doing so, it is possible to set combinations of ink droplets discharged from the nozzle in far more stages.

[0022] Now, the embodiments of the present invention will be described in detail with reference to the accompanying drawings, in which:

FIG. 1 is a perspective cross-sectional view of the print head in the first embodiment according to the present invention;
FIG. 2 is a block diagram of a drive circuit driving a print head according to the present invention;
FIG. 3 is a flow chart showing the process of driving the print head by a drive circuit of FIG. 2;
FIG. 4 shows an example of drive waveforms of piezoelectric transducers in the first embodiment according to the present invention;
FIG. 5 shows an example of a drive waveform selected in case of discharging small drops of ink;
FIG. 6 shows an example of a drive waveform selected in case of discharging large drops of ink;
FIG. 7 is a perspective cross-sectional view of a print head in the second embodiment according to the present invention;
FIG. 8 is an example of a block diagram of a drive circuit driving the print head of FIG. 7;
FIG. 9 is a flow chart showing the process of driving the print head by a drive circuit of FIG. 7
FIG. 10 shows an example of a waveform outputted from a waveform generation circuit shown in FIG. 8;
FIG. 11 shows an example of a waveform outputted from a drive waveform attenuation circuit shown in FIG. 8 when the waveform of FIG. 10 is inputted;
FIG. 12 shows an example of waveforms applied to the respective piezoelectric transducers by the drive circuit shown in FIG. 8; and
FIG. 13 is a block diagram of ink channels for a conventional print head.

[0023] FIG. 1 is a perspective view showing the constitution of a print head in the first embodiment according to the present invention.

[0024] As shown therein, the print head consists of a nozzle plate 4, a head substrate and a diaphragm 2 on which a plurality of piezoelectric transducers 1a, 1b and 1c are provided.

[0025] An ink pool 8 and pressure chambers 6a, 6b, 6c connected to the ink pool 8 through the supply port 7a, 7b, 7c are formed on the upper surface of the head substrate. If the head substrate is formed out of a dry film on a base such as an SUS by means of photolithography, the pressure chambers and supply path can be easily formed into desired shapes. Alternatively, if the substrate is formed out of ceramic by means of integral burning, the rigidity of the pressure chambers can increase and pressurizing energy loss can be reduced.

[0026] Between a nozzle 5 and the ink pool 8, a plurality of pressure chambers 6a, 6b and 6c are substantially aligned in series and connected to the nozzle 5.

[0027] The pressure chambers 6a, 6b and 6c are formed to have a predetermined uniform depth. If the pressure chambers 6a, 6b and 6c have large areas corresponding to the diaphragm 2 with respect to the heights of the chambers, it is possible to obtain sufficient pressure even with a single layered piezoelectric transducer with small displacement amount. In addition, it is preferable that corners R are provided in respective corners of the pressure chambers so as not to keep bubble remaining in the chambers.

[0028] Supply ports 7a, 7b and 7c each having a predetermined length and a narrower width are provided in connecting portions between the respective pressure chambers 6a, 6b and 6c and the ink pool 8, respectively, to maintain pressurizing force within the chambers.

[0029] The cross-section area and length of a supply port are determined by the relationship between pressurizing force loss within a pressure chamber and ink refill time after ink is supplied. Since they contradict against each other, they need to be determined to obtain desired discharge characteristics.

[0030] The connecting portions between the pressure chambers 6a, 6b, 6c and the supply ports 7a, 7b and 7c are provided with tapered portions or corner R portions as required so as to prevent cavitations due to the generation of eddy and sharp change of pressure. It is noted that the tapered or corner R portions may be provided in depth direction.

[0031] Also, tapered or corner portions R may be formed in both thickness and width directions.

[0032] The directions of the supply ports in front or back of the respective pressure chambers 6a, 6b and 6c are oriented in the same direction.

[0033] The shape of the supply ports 7a, 7b, 7c allows pressurizing energy generated within the respective pressure chamber 6a, 6b and 6c to efficiently act on the discharge of ink.

[0034] The diaphragm 2 is provided to propagate pressuring force of the piezoelectric transducers 1a, 1b, 1c to ink within pressure chambers. The diaphragm 2 is made of SUS material or the like having only the portion, to which the piezoelectric transducers 1a, 1b, 1c are attached, formed to be sufficiently thin by means of, for example, electroforming so as to propagate pressurizing force to ink within the pressure chambers without preventing the deformation of the piezoelectric transducer 1a.

[0035] The piezoelectric transducers 1a, 1b and 1c for converting electric signals to mechanical energy corresponding to the respective pressure chamber 6a, 6b and 6c are connected to the diaphragm 2. In addition, signal lines 9a, 9b, 9c and 10 for transmitting electric signals to these piezoelectric transducers are formed on the surface of the diaphragm 2.

[0036] Next, description Will be given to the drive circuit for driving the print head according to the present invention with reference to FIG. 2.

[0037] A waveform generation circuit A 12 which generates waveforms to discharge large ink droplets, a waveform generation circuit B 13 which generates waveforms to discharge middle-size ink droplets and a waveform generation circuit C 14 which generates waveforms to discharge small ink droplets are connected to a switch 15. Output from the selected circuit by the switch 15 is supplied to the piezoelectric transducer 1c of the pressure chamber closest to the ink pool 8 through the switch 17. A waveform delayed from a drive waveform applied to the piezoelectric transducer 1c through a delay circuit 16 for generating a delay by 1/2 of the natural period of pressure wave in the pressure chambers 6a, 6b, 6c is applied to the piezoelectric transducer 1b closer to the nozzle than the transducer 1c through the switch 17. The drive waveform outputted from the delay circuit 16 is further inputted into another delay circuit and delayed. The delayed drive waveform is then applied to the piezoelectric transducer 1a closest to the nozzle 5. While referring to an ink droplet volume table 19, switches 15 and 17 are selected by a waveform and device selection circuit 18 so as to drive necessary piezoelectric transducers with the most suitable drive waveforms for obtaining desired ink droplets.

[0038] The process of driving the piezoelectric transducers in the first embodiment will be described with reference to FIG. 3.

[0039] Ink is supplied from the ink pool 8 through a plurality of supply paths and pressure chambers to the nozzle 5 and is filled therein. First, a waveform and device selection circuit 18 calculates ink droplet volume to be discharged from respective nozzles connected to respective rows of pressure chambers (step S1). Next, based on respective ink droplet volume to be discharged, a waveform and device selection circuit 18 selects waveforms and piezoelectric transducers to apply the drive waveform (step S2). A waveform and device selection circuit 18 may be connected to, for example, a ink droplet volume table 19 storing the relations between ink droplet volume to be discharged and waveforms and piezoelectric transducers to be selected, and select the appropriate drive waveform and piezoelectric transducer to discharge the ink droplet volume required. The number N of the pressure chamber to be operated is set to 1 (step S3). A waveform and device selection circuit 18 judges whether the piezoelectric transducer of the pressure chamber of No. N is one selected in the step S2 (step S4). If the piezoelectric transducer is to be selected, a waveform and device selection circuit 18 applies the drive waveform selected by the switch 15 to the piezoelectric transducer of the pressure chamber N (step S5). That is to say, a drive waveform selected by the switch 15 is applied, as a print signal, to the piezoelectric transducer 1c opposite to the pressure chamber 6c in closest proximity of the ink pool 8 through the signal line 9c. The voltage of the drive waveform, for example, may increase linearly from 0V to a predetermined drive voltage at predetermined rise time and is held to have a predetermined maximum drive voltage for a predetermined time period, as shown in FIG. 4. The drive of the drive waveform linearly may fall from the predetermined voltage to 0V at predetermined fall time, as shown in FIG. 4.

[0040] In this way, a pressure wave applied through the diaphragm 2 by the piezoelectric transducer 1c propagates throughout the ink within the pressure chamber 6c. The pressure wave propagates to the adjacent pressure chamber 6b through the supply port 7b.

[0041] If the piezoelectric transducer of the pressure chamber N is judged to be different from the one selected in step S4, a waveform and device selection circuit 18 does not applies the drive waveform selected by the switch 15 to the piezoelectric transducer of the pressure chamber N.

[0042] Next, a waveform and device selection circuit 18 increments the number N. That is, the next pressure chamber for the nozzle becomes the object to be operated (step S6). A waveform and device selection circuit 18 judges whether the piezoelectric transducer of the pressure chamber N is one selected in the step S2 (step S7) If the piezoelectric transducer of the pressure chamber N is one selected, a delay circuit 16 forms a waveform delayed in phase by 1/2 of the natural period of the pressure wave in the pressure chamber N compared to the drive waveform applied to the pressure chamber N-1 (step S8). Output from the delay circuit 16 is applied to the piezoelectric transducer of the pressure chamber N (step S9) That is to say, the piezoelectric transducer 1b opposite to the pressure chamber 6b next to the pressure chamber 6c is applied with the drive waveform 11b with phase difference as shown in FIG. 4, for example. If the piezoelectric transducer of the pressure chamber N is judged to be different from the one selected in step S7, a waveform and device selection circuit 18 does not applies the drive waveform selected by the switch 15 to the piezoelectric transducer of he pressure chamber N.

[0043] A waveform and device selection circuit 18 judges whether the piezoelectric transducer of the pressure chamber N is last one which connects to the nozzle (step S10). If the piezoelectric transducer of the pressure chamber N is not last one, a waveform and device selection circuit 18 increments the number N (step S11) and return to the step S7.

[0044] It is noted that drive waveforms 11a, 11b and 11c applied to the piezoelectric transducers 1a, 1b and 1c corresponding to the respective pressure chambers may be the same as shown in FIG. 4. In addition, phase differences given to these drive waveforms are 1/2 time difference of fundamental natural time periods for the pressure waves in the respective pressure chambers. By sequentially driving the piezoelectric transducers with different phases given to the waveforms in this way, pressurizing energy generated within a pressure chamber propagates throughout ink within the pressure chamber from the supply port. As soon as the pressurizing energy propagates to the supply port connected to the next pressure chamber, the piezoelectric transducer of the pressure chamber is driven and provided with pressure energy corresponding to the drive displacement amount.

[0045] The phase difference given to the drive wave form may be taken as 1/2 time difference of n-th natural period which is one n-th, where n is an integer, of the basic natural period for the pressure waves for the respective pressure chambers or as 1/2 time difference of n-th natural period considering that pressure energy is added almost in the same manner. It is noted that it is most efficient to use the phase difference based on the fundamental natural period.

[0046] Lastly, the drive wave form 11a having a phase difference is applied to the piezoelectric transducer 1a opposite to the pressure chamber 6a connected to the nozzle 5. The pressure energy within the pressure chamber 6a is added to the pressuring energy propagating from the pressure chamber 6b. If the combined energy reaches the nozzle 5, an ink cylinder protrudes from the nozzle 5 and ink is discharged therefrom. The quantity of ink within the pressure chamber 6a is reduced due to the discharge of ink. Ink is then supplied from the ink pool 8 through the ink supply paths 7a, 7b, 7c and pressure chambers 6b, 6c into the pressure chamber by the capillary action of the nozzle 5 and the quantity of ink is recovered to the original level, thus completing a series of operations.

[0047] Thus, if 3 pressure chambers are included in a respective row, and all of the three piezoelectric transducers are driven with drive waveforms for largest ink droplets, pressurizing energy almost three times as large as that in case of a single pressure chamber is applied to ink. Due to this, ink droplets three times as large as the conventional largest ink droplet can be discharged. In addition, if only one piezoelectric transducer is driven under the drive condition that the smallest ink droplets are discharged, the same quantity of ink droplets as that of the conventional smallest ink droplets can be discharged. The ink droplets discharged from one nozzle can be stably adjusted within a wide range.

[0048] Next, the operation of controlling the size of ink droplets discharged from the nozzle 5 by the drive waveforms of the piezoelectric transducers will be described with reference to FIGS. 5 and 6.

[0049] FIG. 5 shows a waveform in a case where small ink droplets are discharged. FIG. 6 shows a waveform in a case where large ink droplets are discharged.

[0050] Drive displacement amount is set by changing pressure energy, more specifically, by changing voltage waveforms applied to the piezoelectric transducers. To discharge small drops of ink, drive voltage is increased, drive time is shortened and rise time and fall time are shortened as shown in FIG. 5. Conversely, to discharge large drops of ink, drive voltage is decreased, drive time is lengthened and rise and fall time are lengthened as shown in FIG. 6.

[0051] Even if the size of an ink droplet is variable, the ink droplet discharge rate should not be changed between a case where small drops of ink are discharged and a case where large drops of ink are discharged so as to make the ink droplet position constant.

[0052] In an ink-jet printer employing the ink-jet print head of the present invention, ink droplets can be adjusted by changing the number and combination of selected piezoelectric transducers for applying drive waveforms, in a multistage manner stably or without providing a drive circuit for generating many drive waveform patterns.

[0053] If discharging ink droplets closer to smallest ink droplets, only the piezoelectric transducer of the pressure chamber closest to the nozzle is applied with a drive waveform to thereby change the waveform, while the remaining two piezoelectric transducers are not applied with drive waveforms.

[0054] If discharging ink droplets closer to largest ink droplets, the piezoelectric transducers of all of the pressure chambers are applied with drive waveforms to thereby change the waveforms.

[0055] If discharging middle-sized ink droplets, the piezoelectric transducer 1a of the pressure chamber 6a closest to the nozzle 5 and one of the piezoelectric transducers of the remaining two pressure chambers are applied with drive waveforms to thereby change the waveforms. The piezoelectric transducer of the remaining pressure chamber is not applied with a drive waveform. If the pressure chamber 6c farthest from the nozzle is selected, energy loss exists since pressure wave passes through the supply port 7b until pressure wave propagates to the pressure chamber 6a closest to the nozzle. For that reason, the size of ink droplets applied to the pressure chamber 6a is smaller than that applied to the pressure chamber 6b even if the same energy is applied to them.

[0056] If the largest ink droplets in case of applying a drive waveform only to one piezoelectric transducer are larger than the smallest ink droplets in case of applying drive waveforms to two piezoelectric transducers, or if the largest ink droplets in case of applying drive waveforms to two piezoelectric transducers are larger than the smallest ink droplets in case of applying drive waveforms to three piezoelectric transducers, then the combination of the number of drive transducers and drive waveforms, by which ink droplets closest to desired ink droplets are obtained, is selected and the piezoelectric transducers in accordance with the selected number of the drive transducers are applied with selected drive waveforms.

[0057] As described above, according to the present invention, a plurality of pressure chambers necessary to discharge micro-drops and having short natural periods are coupled to one another. This makes it possible to discharge micro-drops to large drops from a single nozzle. Owing to this, it is possible to obtain high-speed, inexpensive, high quality print outputs without the need to overstrike on a dot and use many-valued density ink to express an image by gradations.

[0058] In this embodiment, the piezoelectric transducers are applied with the same drive waveforms which are delayed respectively. It is also possible to select different waveforms and apply them to the piezoelectric transducers. By doing so, far more types of ink droplets can be discharged.

[0059] In this embodiment, a piezoelectric transducer is used as a transducer for converting an electric signal for generating pressurizing force in the pressure chamber 6 into mechanical energy. The piezoelectric transducer may be a single layered piezoelectric transducer or multi-layered piezoelectric transducer.

[0060] Moreover, in this embodiment, three sets of pressure chambers and supply ports are connected in series. At least two sets suffice to provide the same advantage.

[0061] Next, the second embodiment of the present invention will be described in detail with reference to the accompanying drawings.

[0062] FIG. 7 is a perspective cross-sectional view showing the structure of a print head in the second embodiment according to the present invention. The print head in this embodiment differs from that in the first embodiment in that three pressure chambers 26a, 26b and 26c coupled to one another through supply ports 7 are formed in different sizes. For instance, as shown in FIG. 7, unlike the first embodiment, the sizes of pressure chambers are set smaller so that the natural periods of pressure waves are made shorter as the pressure chambers are closer to the nozzle 5. In other words, the sizes of the pressure chambers are set such that the natural period of pressure wave in the pressure chamber 26b closer to the nozzle 5 than the pressure chamber 26c adjacent to an ink pool 8 is shorter than that in the pressure chamber 26c and that the pressure wave natural period in the pressure chamber 6a closer to the nozzle 5 than the pressure chamber 26b is shorter than that in the pressure chamber 26b. The sizes of piezoelectric transducers 21a, 21b and 21c driving the pressure chambers 26a, 26b and 26c, respectively are set according to the sizes of the corresponding pressure chambers.

[0063] Additionally, a print head drive circuit in the second embodiment according to the present invention differs from that in the first embodiment in that the piezoelectric transducers 21a, 21b and 21c are applied with drive waveforms of different maximum voltages. In this embodiment, as shown in, for instance, FIG. 8, drive waveform attenuation circuits 32 and 33 for attenuating the maximum voltages of drive waveforms are provided between switches 17 connected to the piezoelectric transducers 21a, 21b and delay circuits 16 for delaying the timing of a voltage waveform outputted from a waveform generation circuit 31, respectively. This print head drive circuit shown in FIG. 8 is also provided with a device and maximum voltage selection circuit 34, which selects the piezoelectric transducers to apply the voltage waveform among a plurality of piezoelectric transducers 21a, 21b, 21c and selects maximum voltages of applied drive waveforms by setting respective attenuation ratios at drive waveform attenuation circuits 32, 33. The waveform generation circuit 31 may have the three waveform generation circuits described in the first embodiment contained therein and a drive waveform generated from one of the contained circuits may be selected by a selection circuit which is not shown. Needless to say, the waveform generation circuit 31 may be structured to output only one type of waveform.

[0064] Next, the process of driving the piezoelectric transducers in this embodiment will be described with reference to FIG. 9.

[0065] First, a device and maximum voltage selection circuit 34 calculates ink droplet volume to be discharged from respective nozzles connected to respective pressure chamber rows (step S1). Next, based on respective ink droplet volume to be discharged, a device and maximum voltage selection circuit 34 selects piezoelectric transducers to apply the drive waveform and maximum voltages of voltage waveform to be applied to these selected piezoelectric transducers (step S21). The number N of the pressure chamber to be operated is set to 1 (step S3). A device and maximum voltage selection circuit 34 judges whether the piezoelectric transducer of the pressure chamber of No. N is one selected in the step S2 (step S4). If the piezoelectric transducer is to be selected, a device and maximum voltage selection circuit 34 applies the drive waveform having the selected maximum voltage to the piezoelectric transducer of the pressure chamber N (step S22).

[0066] If the piezoelectric transducer of the pressure chamber N is judged to be different from the one selected in step S4, a device and maximum voltage selection circuit 34 does not applies the drive waveform to the piezoelectric transducer of the pressure chamber N.

[0067] Next, a device and maximum voltage selection circuit 34 increments the number N. That is, the next pressure chamber for the nozzle becomes the object to be operated (step S6). A device and maximum voltage selection circuit 34 judges whether the piezoelectric transducer of the pressure chamber N is one selected in the step S2 (step S7). If the piezoelectric transducer of the pressure chamber N is to be selected, a delay circuit 16 forms a waveform having the selected maximum voltage and delayed in phase by 1/2 of the natural period of the pressure wave in the pressure chamber N with comparison to the drive waveform applied to the pressure chamber N-1 (step S23). The formed drive waveform is applied to the piezoelectric transducer of the pressure chamber N (step S9) If the piezoelectric transducer of the pressure chamber N is judged to be different from the one selected in step S7, a device and maximum voltage selection circuit 34 does not applies the drive waveform to the piezoelectric transducer of the pressure chamber N. A device and maximum voltage selection circuit 34 judges whether the piezoelectric transducer of the pressure chamber N is last one connected to the nozzle (step S10). If the piezoelectric transducer of the pressure chamber N is not last one, a waveform and device selection circuit 18 increments the number N (step S11) and return to the step S7. The waveform generation circuit 31 may include 3 waveform generation circuits and switch as described in the first embodiment. The waveform generation circuit 31 may output only one waveform, too.

[0068] When a waveform as shown in, for example, FIG. 10 is inputted, the drive waveform attenuation circuit 32 outputs a waveform which maximum voltage is attenuated while time from the start of the rise of the inputted waveform until the end of the fall thereof and rise/fall voltage gradients are not changed.

[0069] The print head drive circuit shown in FIG. 8 respectively applies drive waveforms 41a, 41b and 41c shown in FIG. 12 to the piezoelectric transducers 21a, 21b, 21c. The drive waveform 41b is delayed by 1/2 of the natural period for the pressure chamber 26b with respect to the drive waveform 41c by the delay circuit 16 and the maximum voltage of the drive waveform 41b is attenuated by the drive waveform attenuation circuit 32. The drive waveform 41a is delayed by 1/2 of the natural period for the pressure chamber 26a with respect to the waveform 41b by the delay circuit 16 and the maximum voltage of the waveform 41a is attenuated more greatly than the waveform 41b by the drive waveform attenuation circuit 33.

[0070] The maximum voltages of the drive waveforms applied to the piezoelectric transducers 21a and 21b are attenuated more greatly than the maximum voltage of the drive waveform applied to the piezoelectric transducer 21c. By doing so, the piezoelectric transducers 21a, 21b and 21c corresponding to the respective pressure chambers are applied with waveforms of different maximum voltages.

[0071] The pressure chambers have different sizes and the settings of maximum voltages of drive waveforms are different, thereby allowing the combination of the types of ink droplets to be freely selected.

[0072] As described so far, according to the present invention, plural sets of pressure chambers and supply ports are arranged to be coupled to one another in series between the nozzle and the ink pool. In addition, the piezoelectric transducers corresponding to the respective pressure chambers are arranged. With this structure, it is possible to drive the selected piezoelectric transducers with selected drive waveforms having phase differences so as to add driving power in respective pressure chambers. Besides, if the piezoelectric transducers are selectively driven, it is possible to change diameters of drops from small drops requiring a pressure chamber having a short natural period to large drops requiring great changes in the volume of pressure chambers.

[0073] Moreover, by providing a plurality of pressure chambers coupled in series with different natural periods, or by applying the piezoelectric transducers of the pressure chambers coupled in series with waveforms of different maximum voltages, it is possible to arbitrarily set the combination of ink droplets discharged.

Claims

1. An ink-jet print head, comprising:

    a plurality of pressure chamber rows formed by connecting a plurality of pressure chambers in series by a plurality of supply paths each having a smaller channel area than said pressure chamber;
    a plurality of piezoelectric transducers provided in the pressure chambers, respectively and applied with voltage waveforms independently of one another;
    an ink pool communicating with a pressure chamber located on one end of each of the pressure chamber rows; and
    a plurality of nozzles each communicating with a pressure chamber located on the other end of the pressure chamber row.

2. The ink-jet print head according to claim 1, wherein said pressure chamber rows include pressure chambers having different natural periods of the pressure waves therein.

3. A method for driving an ink-jet print head including a plurality of pressure chamber rows formed by connecting a plurality of pressure chambers in series by a plurality of supply paths each having a smaller channel area than sad pressure chamber; a plurality of piezoelectric transducers provided in the pressure chambers, respectively and applied with voltage waveforms independently of one another; an ink pool communicating with a first pressure chamber located on one end of each of the pressure chamber rows; and a plurality of nozzles each communicating with a second pressure chamber located on the other end of the pressure chamber row, said driving method comprising:

    selecting piezoelectric transducers to be applied with voltage waveforms for every pressure chamber row;
    sequentially generating voltage waveforms for piezoelectric transducers, from said first pressure chamber to said second pressure chamber, at voltage waveform application timing delayed in phase from that of other pressure chambers connected to one another on an ink pool side, by 1/2 of natural periods of pressure wave in pressure chambers; and
    sequentially applying voltage waveforms generated in said generating step to the piezoelectric transducers selected in said selecting step.

4. The method according to claim 3, wherein said selecting step is further selecting maximum voltages to be applied to the selected piezoelectric transducers among a plurality of predetermined voltages.

5. The method according to claim 3, wherein said selecting step is selecting the piezoelectric transducers based on a combination of piezoelectric transducers capable of providing ink droplets closest to desired ink droplets while referring to a relationship between combinations of piezoelectric transducers applied with said voltage waveforms and the discharged ink droplets.

6. The method according to claim 4, wherein said selecting step is selecting piezoelectric transducers and maximum voltages based on the piezoelectric transducer driving conditions capable of providing ink droplets closest to desired ink droplets while referring to a relationship between the piezoelectric transducer driving conditions and the ink droplets under the conditions, said conditions including combinations of piezoelectric transducers to apply voltage waveform and maximum voltages of voltage waveform to be applied to respective transducers.

7. An ink-jet printer, comprising:

    an ink-jet print head including a plurality of pressure chamber rows formed by connecting a plurality of pressure chambers in series by a plurality of supply paths each having a smaller channel area than said pressure chamber; a plurality of piezoelectric transducers provided in the pressure chambers, respectively and applied with voltage waveforms independently of one another; an ink pool communicating with a pressure chamber located on one end of each of the pressure chamber rows; and a plurality of nozzles each communicating with a pressure chamber located on the other end of the pressure chamber row;
    voltage applied device selection unit for selecting piezoelectric transducers applied with voltage waveforms;
    voltage waveform generating unit for generating voltage waveforms for piezoelectric transducers, from said first pressure chamber to said second pressure chamber, at voltage waveform application timing delayed in phase from that of other pressure chambers connected to one another on an ink pool side, by

1/2 of natural periods of pressure wave in pressure chambers; and

voltage waveform application units for sequentially applying voltage waveforms generated in said voltage waveform generating unit to the piezoelectric transducers selected in said voltage applied device selection unit.

8. An ink-jet printer, comprising:

an ink-jet print head including a plurality of pressure chamber rows formed by connecting a plurality of pressure chambers, having different pressure wave natural periods, in series by a plurality of supply paths each having a smaller channel area than said pressure chamber; a plurality of piezoelectric transducers provided in the pressure chambers, respectively and applied with voltage waveforms independently of one another; an ink pool communicating with a pressure chamber located on one end of each of the pressure chamber rows; and a plurality of nozzles each communicating with a pressure chamber located on the other end of the pressure chamber row;

voltage applied device selection unit for selecting piezoelectric transducers applied with voltage waveforms and maximum voltage of the voltage waveforms applied to the piezoelectric strain;

voltage waveform generating unit for generating voltage waveforms having said maximum voltages for piezoelectric transducers, from said first pressure chamber to said second pressure chamber, at voltage waveform application timing delayed in phase from that of other pressure chambers connected to one another on an ink pool side, by 1/2 of natural periods of pressure wave in pressure chambers; and

voltage waveform application units for sequentially applying voltage waveforms generated in said voltage waveform generating unit to the piezoelectric transducers selected in said voltage applied device selection unit.

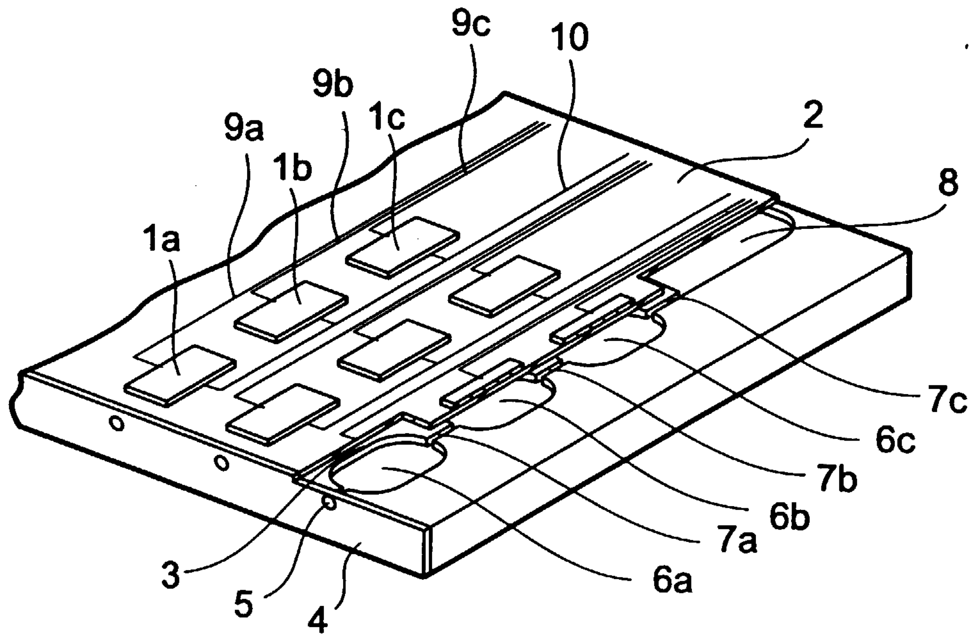

FIG.1

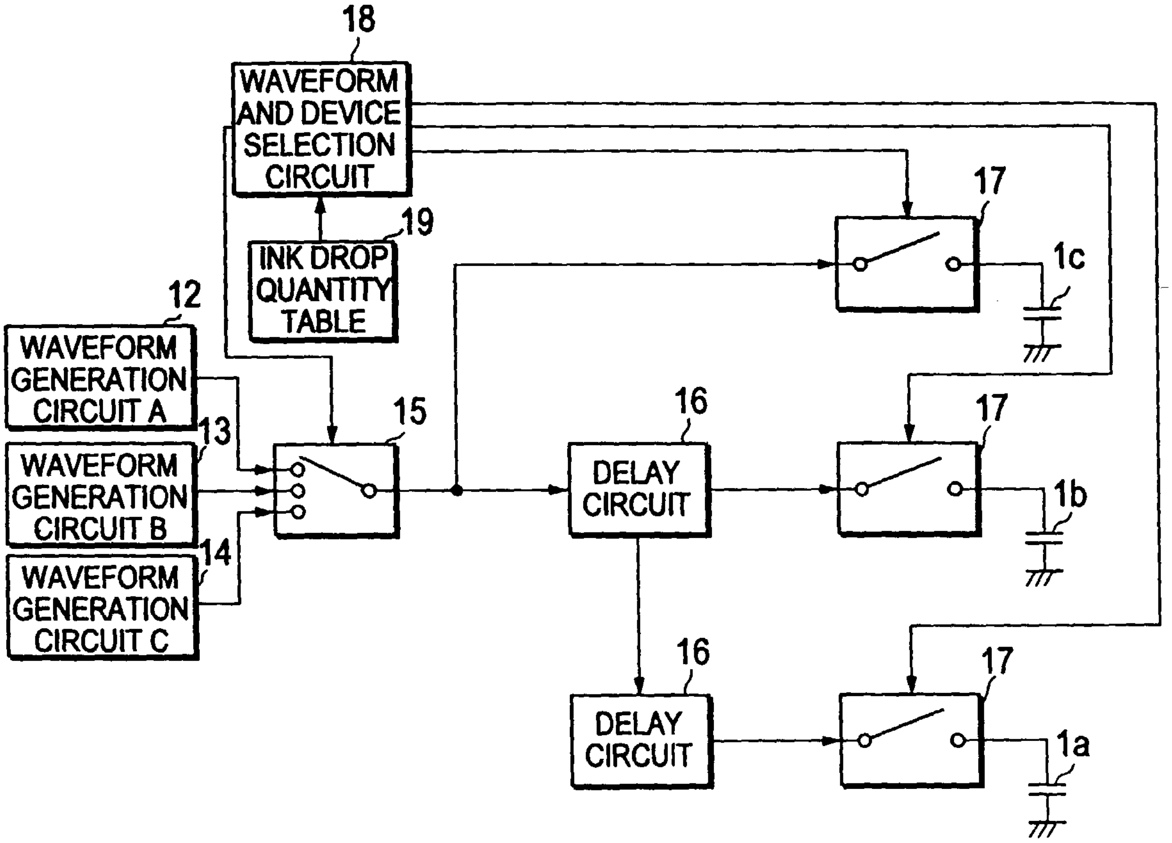
18
WAVEFORM AND DEVICE SELECTION CIRCUIT
19
INK DROP QUANTITY TABLE
12
WAVEFORM GENERATION CIRCUIT A
13
WAVEFORM GENERATION CIRCUIT B
14
WAVEFORM GENERATION CIRCUIT C
15
16
DELAY CIRCUIT
16
DELAY CIRCUIT
17
17
17
1c
1b
1a

FIG.2

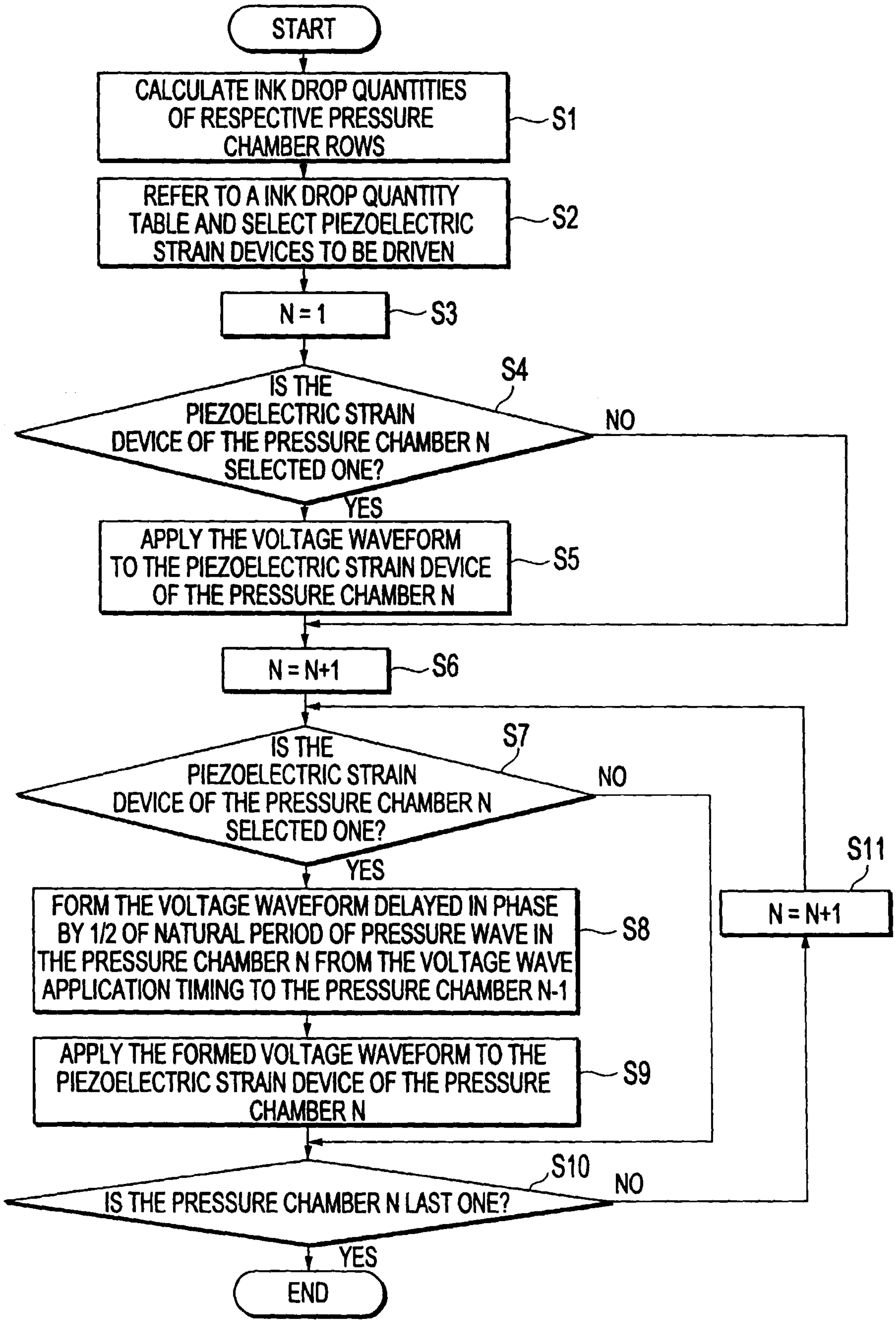
START
CALCULATE INK DROP QUANTITIES OF RESPECTIVE PRESSURE CHAMBER ROWS
S1
REFER TO A INK DROP QUANTITY TABLE AND SELECT PIEZOELECTRIC STRAIN DEVICES TO BE DRIVEN
S2
N = 1
S3
IS THE PIEZOELECTRIC STRAIN DEVICE OF THE PRESSURE CHAMBER N SELECTED ONE?
S4
NO
YES
APPLY THE VOLTAGE WAVEFORM TO THE PIEZOELECTRIC STRAIN DEVICE OF THE PRESSURE CHAMBER N
S5
N = N+1
S6
IS THE PIEZOELECTRIC STRAIN DEVICE OF THE PRESSURE CHAMBER N SELECTED ONE?
S7
NO
YES
FORM THE VOLTAGE WAVEFORM DELAYED IN PHASE BY 1/2 OF NATURAL PERIOD OF PRESSURE WAVE IN THE PRESSURE CHAMBER N FROM THE VOLTAGE WAVE APPLICATION TIMING TO THE PRESSURE CHAMBER N-1
S8
APPLY THE FORMED VOLTAGE WAVEFORM TO THE PIEZOELECTRIC STRAIN DEVICE OF THE PRESSURE CHAMBER N
S9
IS THE PRESSURE CHAMBER N LAST ONE?
S10
NO
YES
END
N = N+1
S11

FIG.3

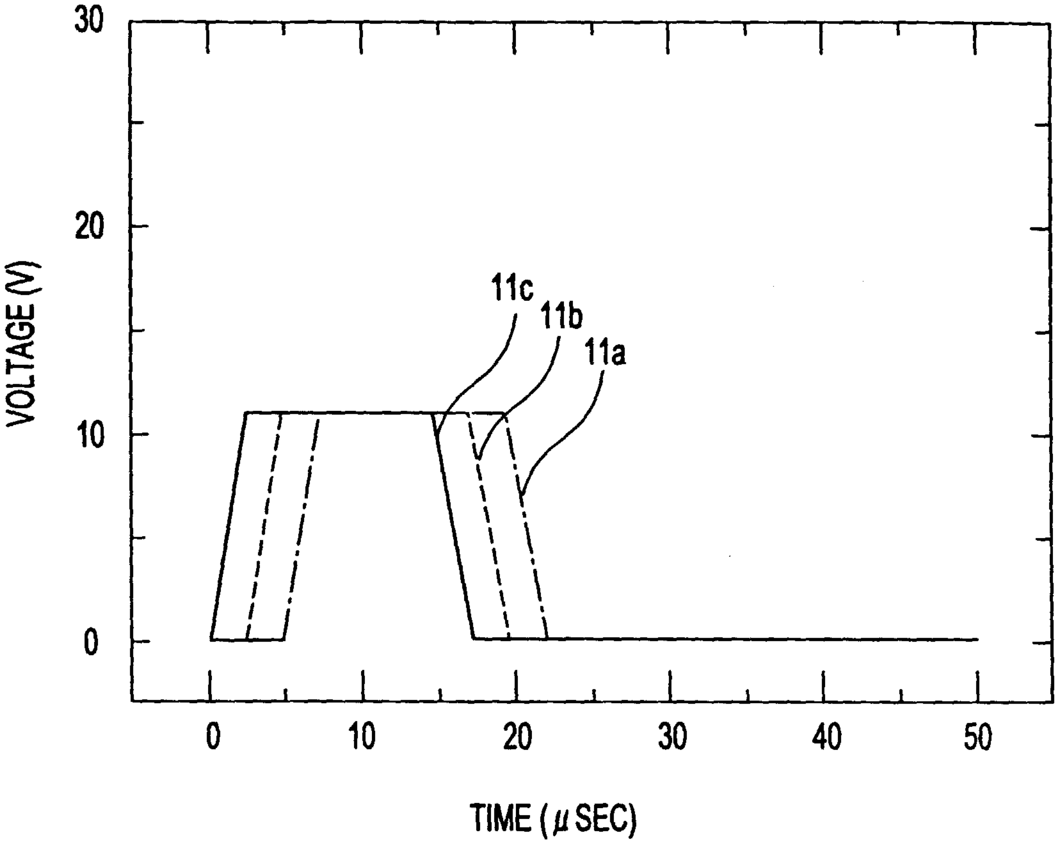

FIG.4

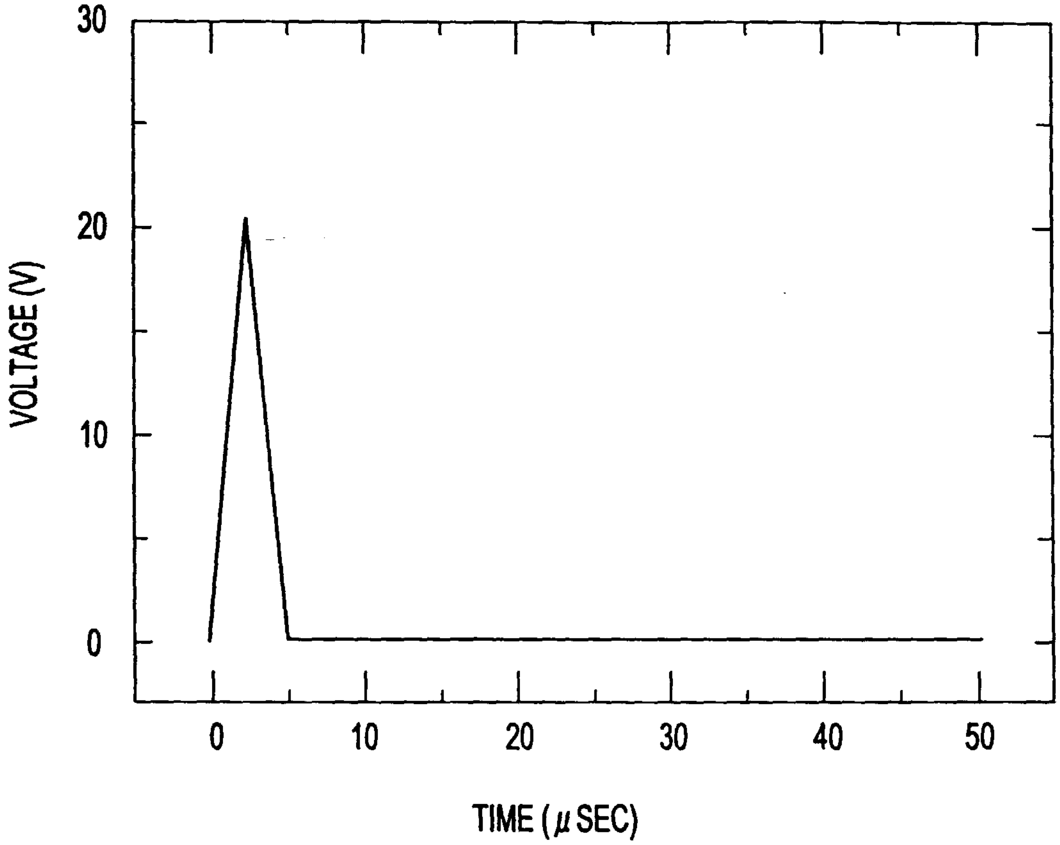

FIG.5

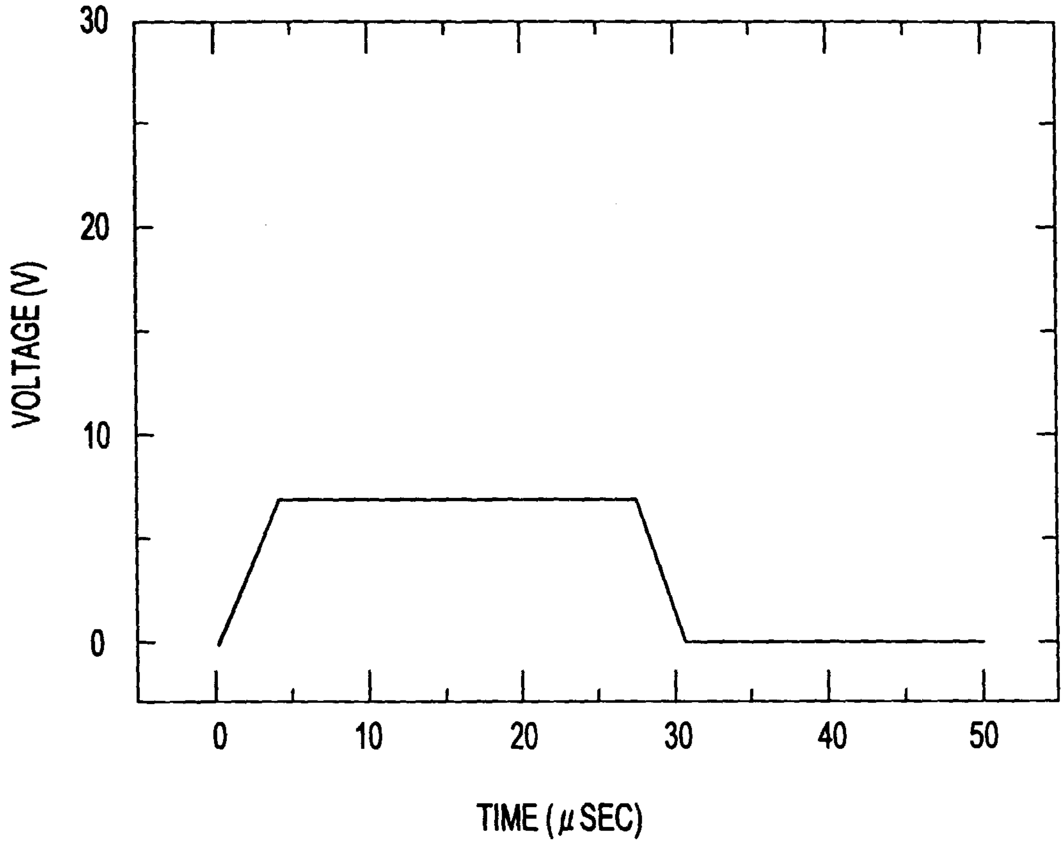

FIG.6

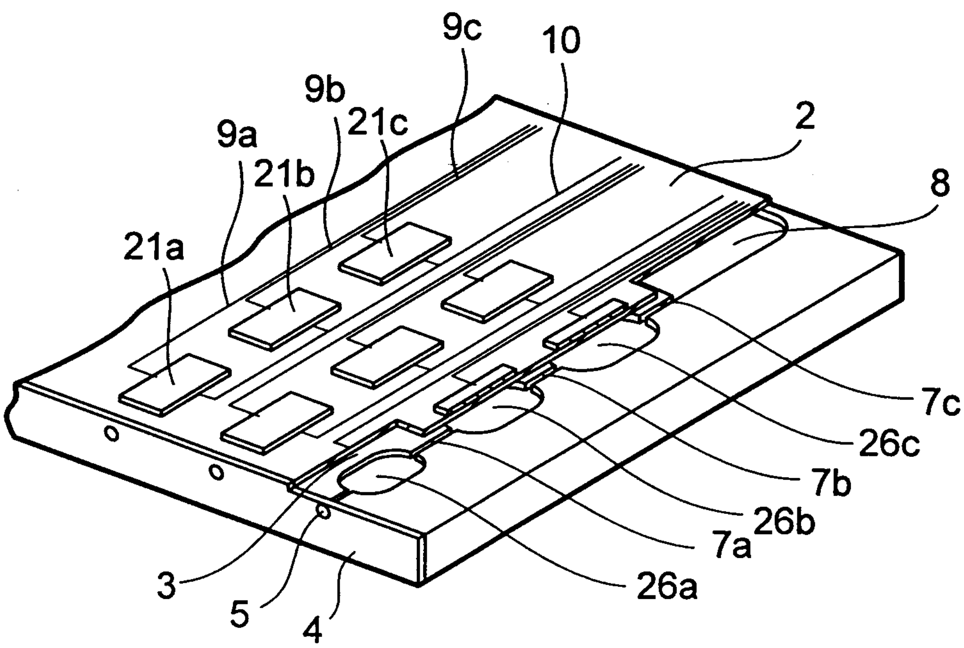

FIG.7

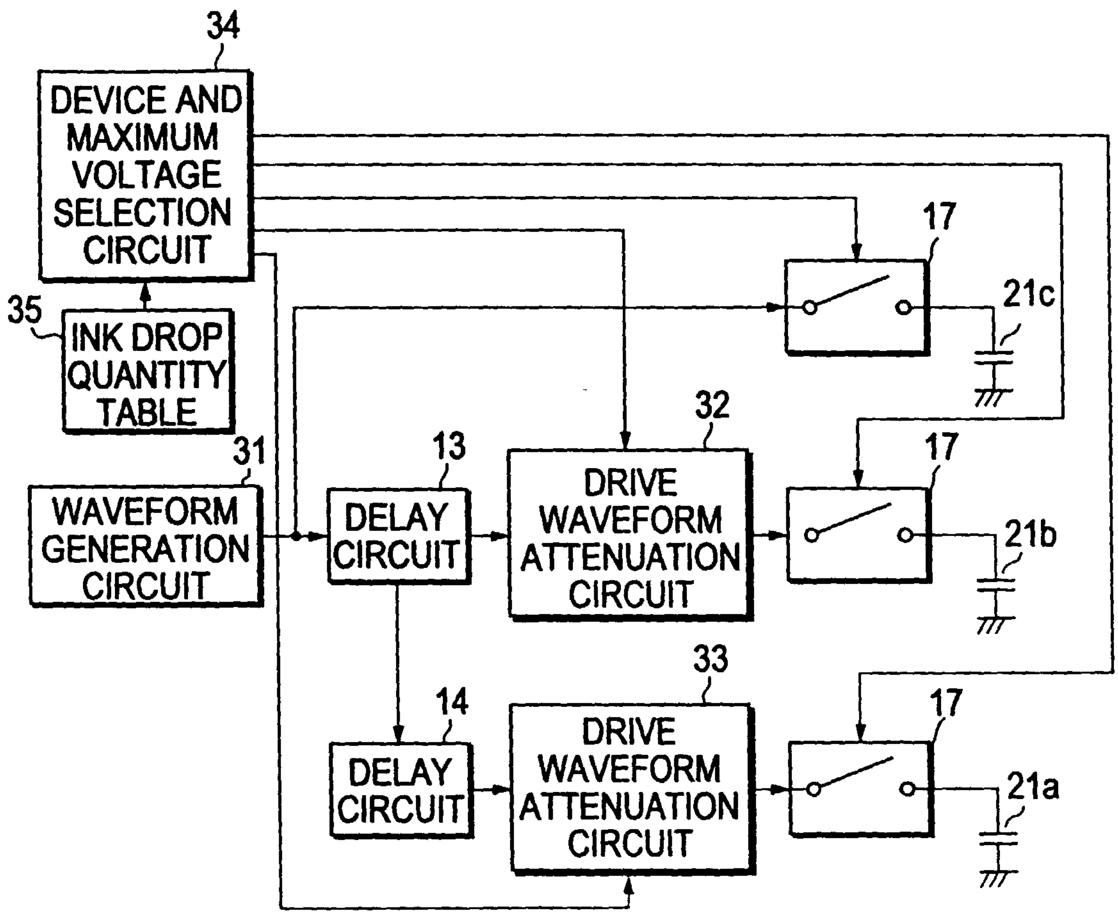
34
DEVICE AND MAXIMUM VOLTAGE SELECTION CIRCUIT
35
INK DROP QUANTITY TABLE
31
WAVEFORM GENERATION CIRCUIT
13
DELAY CIRCUIT
14
DELAY CIRCUIT
32
DRIVE WAVEFORM ATTENUATION CIRCUIT
33
DRIVE WAVEFORM ATTENUATION CIRCUIT
17
17
17
21c
21b
21a

FIG.8

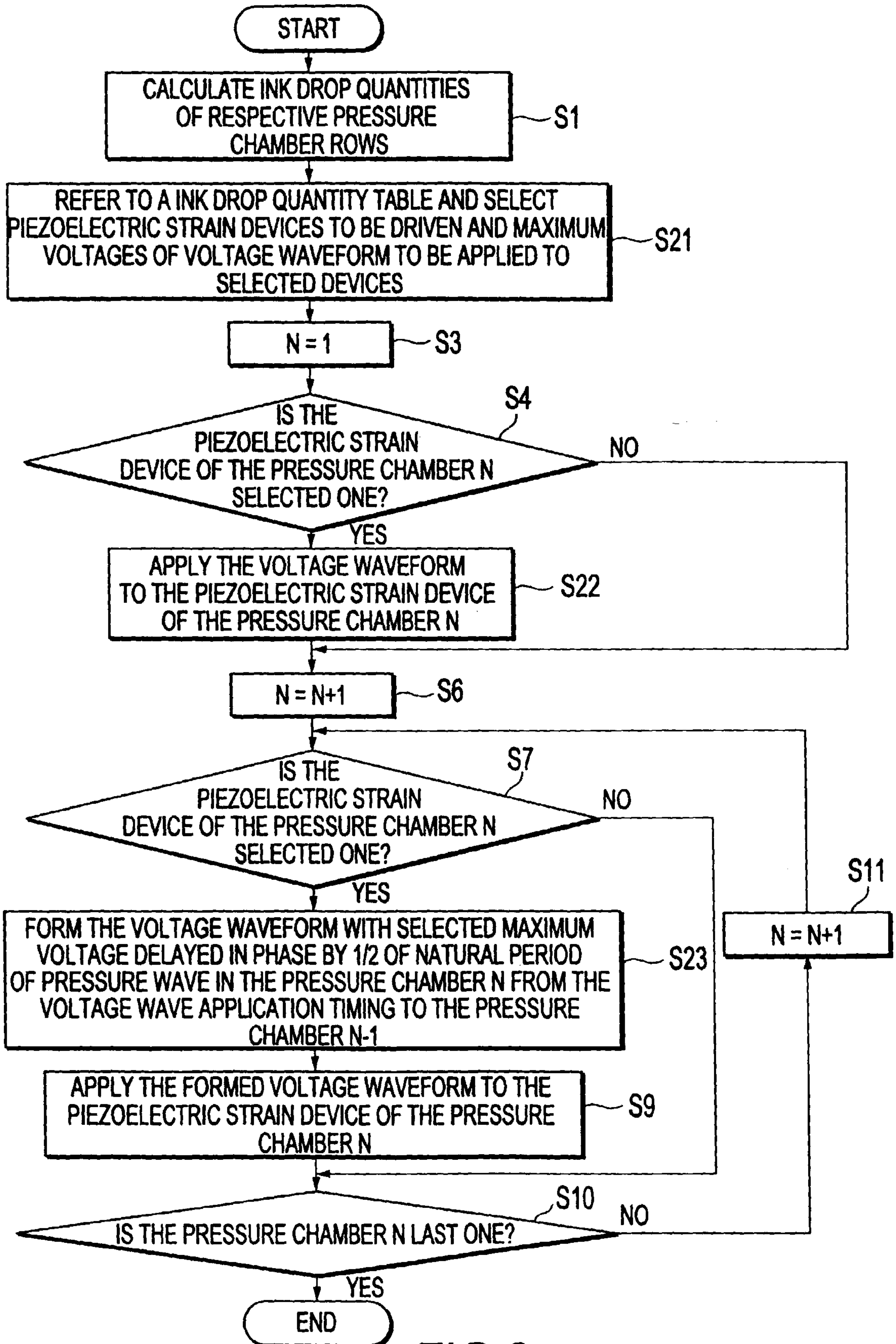
START
CALCULATE INK DROP QUANTITIES OF RESPECTIVE PRESSURE CHAMBER ROWS
S1
REFER TO A INK DROP QUANTITY TABLE AND SELECT PIEZOELECTRIC STRAIN DEVICES TO BE DRIVEN AND MAXIMUM VOLTAGES OF VOLTAGE WAVEFORM TO BE APPLIED TO SELECTED DEVICES
S21
N = 1
S3
IS THE PIEZOELECTRIC STRAIN DEVICE OF THE PRESSURE CHAMBER N SELECTED ONE?
S4
NO
YES
APPLY THE VOLTAGE WAVEFORM TO THE PIEZOELECTRIC STRAIN DEVICE OF THE PRESSURE CHAMBER N
S22
N = N+1
S6
IS THE PIEZOELECTRIC STRAIN DEVICE OF THE PRESSURE CHAMBER N SELECTED ONE?
S7
NO
YES
FORM THE VOLTAGE WAVEFORM WITH SELECTED MAXIMUM VOLTAGE DELAYED IN PHASE BY 1/2 OF NATURAL PERIOD OF PRESSURE WAVE IN THE PRESSURE CHAMBER N FROM THE VOLTAGE WAVE APPLICATION TIMING TO THE PRESSURE CHAMBER N-1
S23
APPLY THE FORMED VOLTAGE WAVEFORM TO THE PIEZOELECTRIC STRAIN DEVICE OF THE PRESSURE CHAMBER N
S9
S11
N = N+1
IS THE PRESSURE CHAMBER N LAST ONE?
S10
NO
YES
END

FIG.9

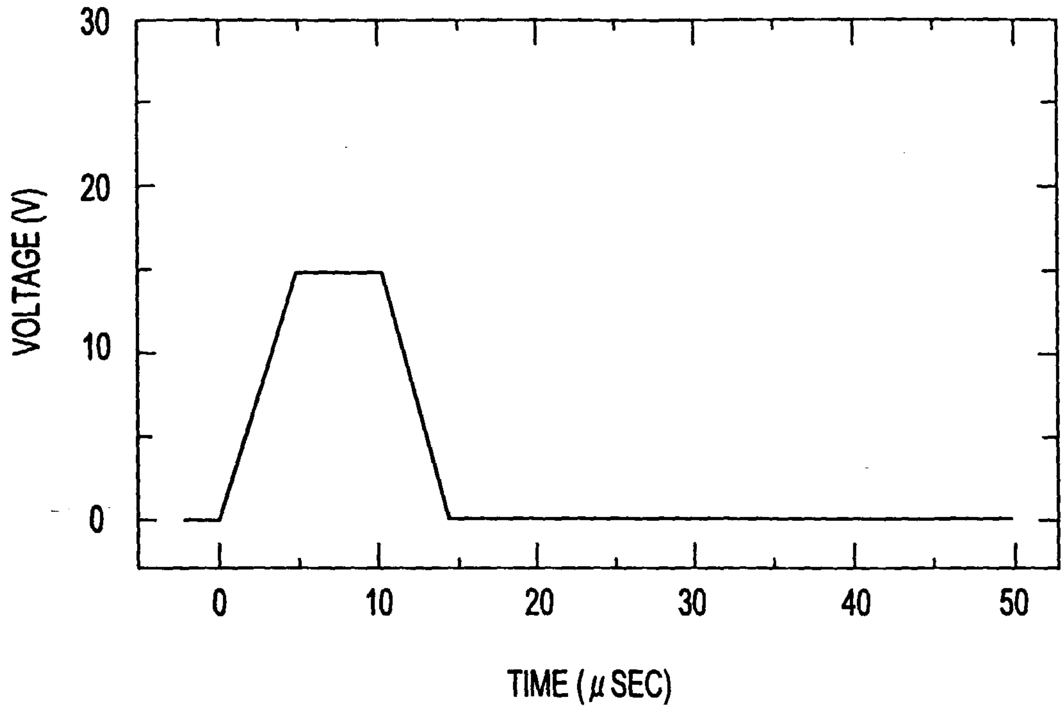
30
20
10
0
VOLTAGE (V)
0
10
20
30
40
50
TIME (μSEC)

FIG.10

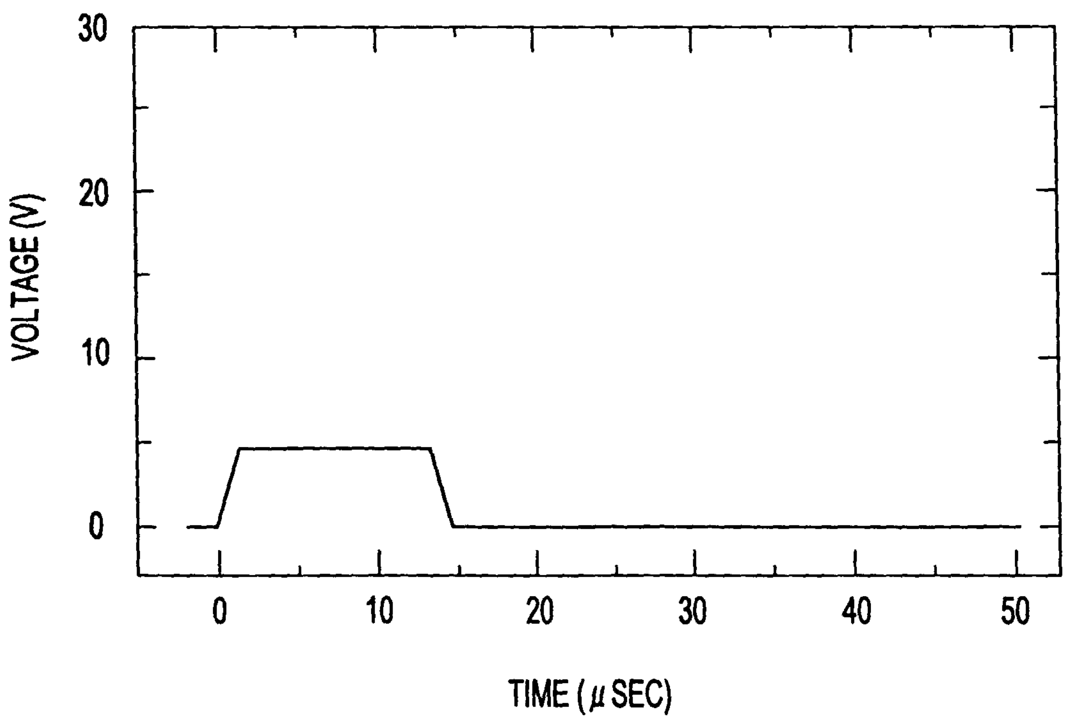
30
20
10
0
VOLTAGE (V)
0
10
20
30
40
50
TIME (μSEC)

FIG.11

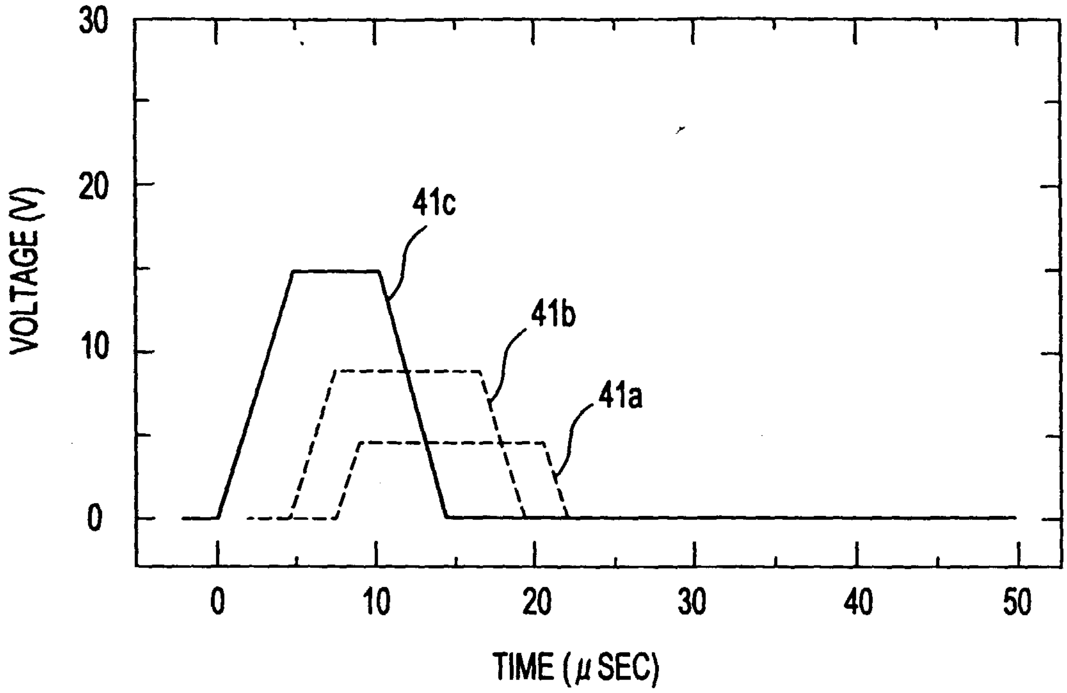
30
20
10
0
VOLTAGE (V)
41c
41b
41a
0
10
20
30
40
50
TIME (μ SEC)

FIG.12

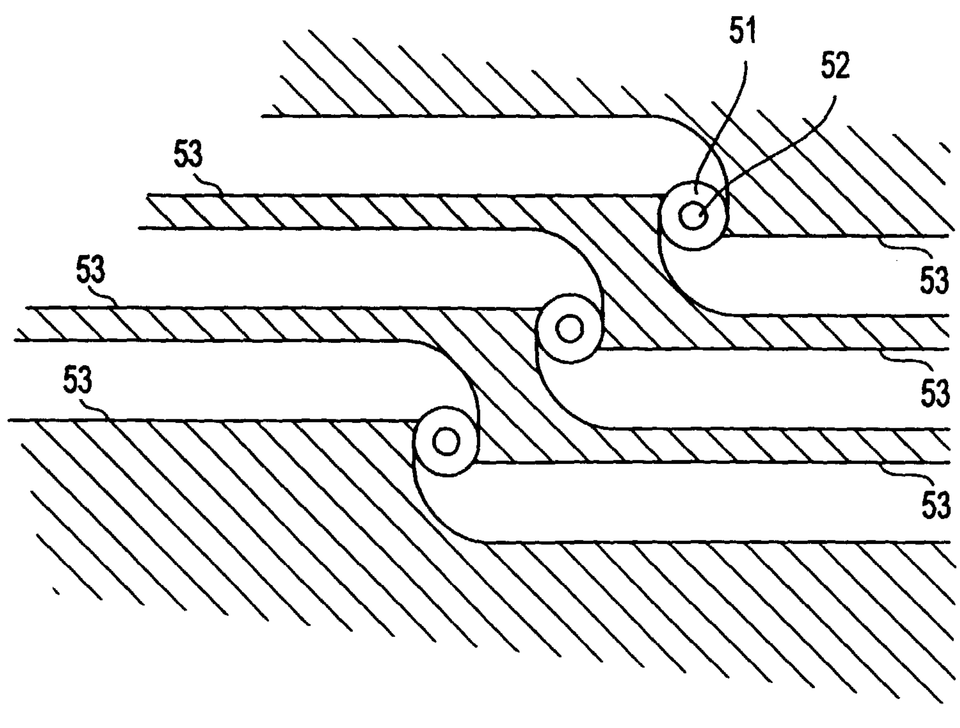
51
52
53
53
53
53
53
53

FIG.13