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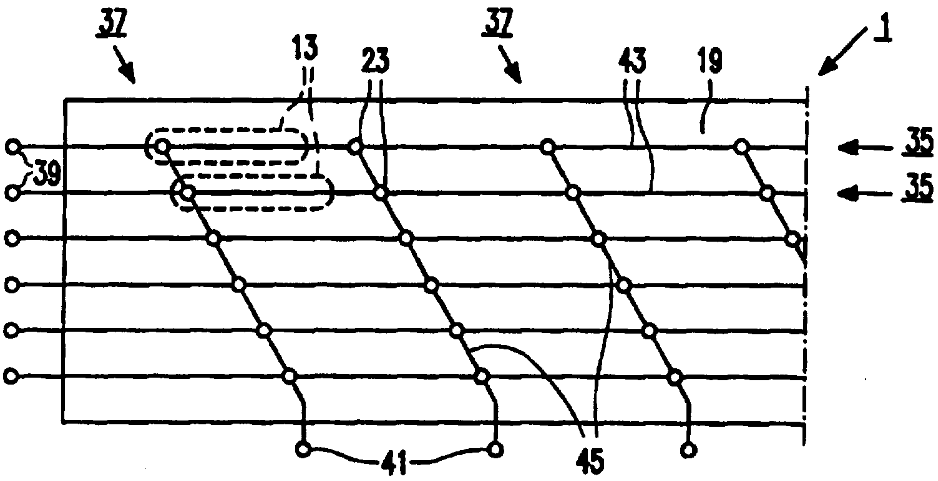
(54) Title: INK JET RECORDING DEVICE

(57) Abstract



The device includes a recording head (1) comprising a plurality of pressure chambers (13), each pressure chamber communicating with a nozzle opening (23), the nozzle openings being arranged in a matrix comprising n rows (35) and m columns (37). A piezoelectric actuator element (7) is associated with each pressure chamber (13), each actuator element comprising a first electrode (9) and a second electrode (11). The volume of the pressure chamber (13) is changed when a voltage is applied between the first and second electrodes (9, 11), the pressure chamber expanding when the first electrode is made positive with respect to the second electrode and contracting when the first electrode is made negative with respect to the second electrode. A droplet of ink is ejected from thenozzle opening (23) if a contraction of the pressure chamber (13) causes a relative decrease in its volume that exceeds a predetermined value. The recording device further includes a control unit (5) for selectively applying predetermined voltage pulses to the first and second electrodes (9, 11) of each actuator element (7). The recording head (1) comprises n first terminals (39) and m second terminals (41), the first electrodes (9) of the actuator elements (7) associated with the pressure chambers (13) that have nozzle openings (23) in a common row (35) being electrically connected to one of the first terminals and the second electrodes (11) of the actuator elements associated with the pressure chambers that have nozzle openings in a common column (37) being electrically connected to one of the second terminals. The control unit (5) is arranged to selectively provide first voltage pulses (V_i) to the first terminals (39) and to selectively provide second voltage pulses (V_j) to the second terminals (41), the voltage pulses being chosen such that the change in volume of a pressure chamber (13) caused by either a first or a second voltage pulse is insufficient to cause the emission of a droplet of ink, whereas the change in volume caused by the combined effect of a first and a second voltage pulse is sufficient to cause the emission of a droplet of ink.

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Ink jet recording device.

The invention relates to an ink jet recording device including a recording head comprising:
a plurality of pressure chambers, each pressure chamber communicating with an ink reservoir and with a nozzle opening, the nozzle openings being formed as through holes in a nozzle plate that covers the pressure chambers so as to form a wall of each pressure chamber, said nozzle openings being arranged in a matrix comprising n rows and m columns;
a number of piezoelectric actuator elements corresponding to the number of pressure chambers, each actuator element comprising a first electrode and a second electrode, each actuator element being arranged in cooperative relationship with one of the pressure chambers such that the volume of the pressure chamber is changed when a voltage is applied between the first and second electrodes, the pressure chamber expanding when the first electrode is made positive with respect to the second electrode and contracting when the first electrode is made negative with respect to the second electrode, a droplet of ink being emitted from the nozzle opening if a contraction of the pressure chamber causes a relative decrease in its volume that exceeds a predetermined value;
the recording device further including a control unit for selectively applying predetermined voltage pulses to the first and second electrodes of each actuator element.

An ink jet recording device of this type is disclosed in EP-A-0 516 188. The arrangement of the nozzle openings in a matrix has the advantage that recording with a higher resolution can be achieved than would be possible if only a single row of nozzle openings would be used. Due to the finite dimensions of the pressure chambers and the actuator elements the distance between adjacent nozzle openings cannot be made arbitrarily small. Consequently, it is not possible to achieve a density of, for example, three hundred nozzle openings per inch, which would be required for recording with a resolution of three hundred dots per inch (dpi). However, in modern recording devices much higher resolutions (frequently more than 600 dpi) are standard. Such resolutions are possible when the nozzle openings are arranged in a matrix in which the columns are not perpendicular to the rows so that the centres of the nozzle openings of a second row are located halfway between the centres of the nozzle openings in a first row. The resolution is then twice the distance between the centres of the nozzle openings.

Following the same principle, the resolution could be increased p times by using p rows of nozzle openings. It would further be attractive to make the device suitable for colour recording. If for each colour p rows would be used, the number of rows would be n = cp where c is the number of different colours used for recording. Usually, c is equal to four (black and three basic colours). However, in the known recording devices it is very difficult to arrange the nozzle openings in a matrix having more than two rows. The reason for this is that each actuator element has two electrodes to which connections have to be made. Either the first or the second electrodes of all actuator elements can be connected in common to save connections but it must be possible to address the other electrodes individually. Therefore, in a recording head in which the nozzle openings are arranged in a matrix having n rows and m columns nm + 1 connections are required. This would require an extremely high density of conductors leading to the recording head which would make the device expensive and less reliable.

It is an object of the invention to provide a recording device of the kind set forth in which the number of connections to be made to the recording head is significantly reduced. To achieve this object, the device in accordance with the invention is characterized in that the recording head comprises n first terminals and m second terminals, the first electrodes of the actuator elements associated with the pressure chambers that have nozzle openings in a common row being electrically connected to one of the first terminals and the second electrodes of the actuator elements associated with the pressure chambers that have nozzle openings in a common column being electrically connected to one of the second terminals, the control unit being arranged to selectively provide first voltage pulses to the first terminals and to selectively provide second voltage pulses to the second terminals, each voltage pulse having a rise time, a maximum value and a decay time, the voltage pulses being chosen such that the change in volume of a pressure chamber caused by either a first or a second voltage pulse is insufficient to cause the emission of a droplet of ink, whereas the change in volume caused by the combined effect of a first and a second voltage pulse is sufficient to cause the emission of a droplet of ink. The number of connections to be made to the recording head corresponds to the number of terminals which is equal to n + m. This is significantly less than nm + 1.

There is a variety of combinations of first and second voltage pulses that satisfy the demands of the invention. A first embodiment of the device in accordance with the invention is characterized in that the first voltage pulses are positive with respect to a fixed reference potential and the second voltage pulses are negative with respect to the reference potential, each voltage pulse having a relatively long rise time and a relatively short decay time, the maxima of the first and second voltage pulses being substantially coincident in time. In this embodiment the pressure chamber slowly expands to permit the flow of ink to the pressure chamber and then rapidly contracts to eject a droplet of ink through the nozzle opening.

A second embodiment of the device in accordance with the invention is characterized in that the first voltage pulses are negative with respect to a fixed reference potential and the second voltage pulses are positive with respect to the reference potential, each voltage pulse having a relatively short rise time and a relatively long decay time, the maxima of the first and second voltage pulses being substantially coincident in time. In this embodiment a droplet of ink is ejected followed by a slow expansion of the pressure chamber to replenish the ink in the pressure chamber. Preferably, the maximum values of the first and second voltage pulses are substantially equal.

In the first and second embodiments the rising flanks of the combined first and second voltage pulses actively cause a change in volume of the pressure chamber. During the decaying flanks the pressure chamber resumes its original volume due to the elasticity of its walls without the voltage pulses assisting in this process. In a third and a fourth embodiment one of the voltage pulses actively causes the volume change in a first direction whereas the other voltage pulse actively causes the voltage change in the opposite direction. The third embodiment is characterized in that the first and second voltage pulses are positive with respect to a fixed reference potential, the first voltage pulse having a relatively long rise time and a relatively short decay time, the second voltage pulse having a relatively short rise time and a relatively long decay time, the decay time of the first voltage pulse and the rise time of the second voltage pulse substantially coinciding. The fourth embodiment is characterized in that the first and second voltage pulses are negative with respect to a fixed reference potential, the second voltage pulse having a relatively long rise time and a relatively short decay time, the first voltage pulse having a relatively short rise time and a relatively long decay time, the decay time of the second voltage pulse and the rise time of the first voltage pulse substantially coinciding.

A further improved version of the third and fourth embodiments is characterized in that the first and second voltage pulses are chosen such that the potential difference U(t) between the first and second electrodes of an actuator element that receives first and second voltage pulses substantially satisfies the relation $\int U(t)dt = 0$ where t is the time. In this version the net transport of electric charge between the first and second electrodes is substantially equal to zero. This reduces the likelihood of electrochemical processes that could take place between metallic parts of the actuator element that are electrically connected to different ones of the first and second electrodes, in particular if such metallic parts are in contact with an electrically conductive ink.

These and other aspects of the invention will be described in detail hereinafter with respect to the drawing.

Figure 1 is a simplified block diagram of an ink jet recording device according to the invention,

Figure 2 is a cross-section of a part of an ink jet recording head suitable for the device shown in Figure 1,

Figure 3 shows, in combination, the layout of the nozzle plate of the recording head shown in Figure 2 and a schematic representation of the configuration of the connections to the electrodes of the actuator elements of that recording head, and

Figures 4 to 7 are diagrams showing various types of voltage pulses that can be applied to the electrodes of the recording head shown in Figures 2 and 3.

Figure 1 is a block diagram showing only the most essential parts of an ink jet recording device in accordance with the invention. Such a device comprises an ink jet recording head 1, a paper transport mechanism 3 and a control unit 5. The general construction of ink jet printing devices is well known in the art, see for example US-A-3,946,398. The device according to the invention differs from the known devices mainly in the construction of the recording head 1 and in the manner of controlling the recording head.

A part of a cross-section of an example of the recording head 1 is shown in Figure 2. This recording head comprises a plurality of piezoelectric actuator elements 7 in the form of an actuator plate that consists of a plurality of layers of a ceramic piezoelectric material alternated with electrode layers. As shown schematically in Figure 2, the first, third, fifth, etc. electrode layers are connected to a first electrode 9 and the second, fourth, sixth, etc. electrode layers are connected to a second electrode 11. The electrodes 9, 11 receive voltage pulses from the control unit 5 as will be discussed later. Actuator elements of this type are known in the art as ceramic multilayer actuators (CMA's). When a voltage is applied between the electrodes 9 and 11, the dimension of the actuator plate 7 in the vertical direction in Figure 2 is varied. In other words, the actuator plate 7 changes its thickness upon application of a voltage. The direction in which the dimension of a CMA is changed upon application of a voltage is called its active direction. The actuator plate 7 is provided with a recess 13 that forms a pressure chamber. In the embodiment shown in Figure 2, the recess 13 extends through the thickness of the actuator plate so as to connect a first face 15 of the actuator plate 7 to a second face 17 opposite the first face.

A nozzle plate 19 has a first face 21 that is connected to the first face 15 of the actuator plate 7 so as to form a first wall of the pressure chamber 13. The nozzle plate 19 comprises a plurality of nozzle openings 23, one of which is visible in Figure 2. This nozzle opening 23 extends between the pressure chamber 13 and the space surrounding the recording head. The nozzle plate 19 is preferably a thin metal plate in which the nozzle openings 23 have been formed for example by etching, ultrasonic drilling, laser cutting or another known technique.

A base plate 25 has a first face 27 that is connected to the second face 17 of the actuator plate 7 so as to form a second wall of the pressure chamber 13. An ink reservoir 29 communicates with the pressure chamber 13 via an ink supply channel 31. The ink reservoir 29 and the ink supply channel 31 are formed as recesses in the second face 17 of the actuator plate 7, preferably together with the recess 13. The ink reservoir 29 is a relatively wide duct interconnecting the ink supply channels 31. In order to prevent a pressure wave in one of the pressure chambers 13 from causing a rise of pressure in one or more of the other pressure chambers, each ink supply channel 31 comprises a restricted portion 31a that serves as a choke. The first face 27 of the base plate 25 covers the ink reservoir 29 and the ink supply channel 31. The base plate 25 comprises one or more filling channels 33 formed as through-holes (shown in dotted lines in Figure 2) to connect the ink reservoir 29 to an ink storage vessel (not shown).The construction of the recording head 1 from the actuator plate 7, the nozzle plate 19 and the base plate 25 is very simple. More details of the construction of this recording head and other examples of recording heads that are suitable for the device shown in Figure 1 are disclosed in the copending patent specification No. ... (PHN 15.079). Other types of recording heads, such as the types disclosed in EP-A-0 516 188, are also suitable for use in the recording device of Figure 1.

After the recording head 1 has been completed, the ink reservoir 29, the ink supply channels 31 and the pressure chambers 13 are filled with a suitable ink. When a voltage of a predetermined polarity is applied between the electrodes 9 and 11 such that the first electrode 9 is made positive with respect to the second electrode 11, the thickness of the actuator plate 7 increases so that the volume of the pressure chamber 13 grows. As a result of this expansion ink flows from the ink reservoir 29 through the ink supply channel 31 to the pressure chamber 13. When the voltage between the electrodes 9 and 12 is reduced to zero or when its polarity is reversed, the pressure chamber suddenly contracts so that a droplet of ink is ejected through the nozzle 23. A condition for the ejection of a droplet of ink is that the relative volume change $\Delta Q/Q$ exceeds a predetermined value. In this expression Q is the volume at rest of the pressure chamber 13 (the volume when no potential difference exists between the first and second electrodes 9, 11) and ΔQ is the absolute change in volume caused by a change in the voltage between the electrodes. The very small cross-section of the restricted portion 31a of the ink supply channel prevents the flow of ink from the pressure chamber 13 back to the ink reservoir 29 as a result of the contraction of the pressure chamber.

Figure 3 shows the layout of the nozzle plate 19 in which the nozzle openings 23 are arranged in a matrix comprising n rows 35 and m columns 37. In the embodiment shown in Figure 3 the number of rows 35 equals six and the number of columns 37 is not specified. Three columns 37 are shown fully and one partly. Two of the pressure chambers 13 are shown in dotted lines to show their position relative to the nozzle openings 23. Figure 3 also shows very schematically how the first and second electrodes 9, 11 of the actuator elements 7 are connected. The recording head 1 comprises n first terminals 39 and m second terminals 41. Each group of terminals 39, 41 may be formed as a connector that can be connected to a cable that leads to the control unit 5 (Figure 1). The first electrodes 9 of the actuator elements 7 associated with the pressure chambers 13 that have nozzle openings 23 in a common row 35 are electrically connected to one of the first terminals 39 by means of a first line 43 as shown schematically in Figure 3. Likewise, the second electrodes 11 of the actuator elements 7 associated with the pressure chambers 13 that have nozzle openings 23 in a common column 37 are electrically connected to one of the second terminals 41 by means of a second line 45. As a result, the first electrodes 9 in every i^{th} row

35 are connected to the i^{th} first terminal 39 and the second electrodes 11 in every j^{th} column 37 are connected to the j^{th} second terminal 41. The angles between the rows 35 and the columns 37 can be chosen freely. The terms "rows" and "columns" are interchangeable.

The control unit 5 (see Figure 1) may comprise first and second voltage generator means 47a and 47b and switching means 49 (for example, a multiplexer) controlled by a central control element 51. The arrangement is such that the control unit 5 can selectively provide first voltage pulses generated by the first voltage generator means 47a to the first terminals 39 and second voltage pulses generated by the second voltage generator means 47b to the second terminals 41. As will be explained in detail later, each one of these voltage pulses has a rise time, a maximum value and a decay time, the voltage pulses being chosen such that the change in volume of a pressure chamber 13 that is caused by either a first or a second voltage pulse alone is insufficient to cause the emission of a droplet of ink. However, the change in volume caused by the combined effect of a first and a second voltage pulse is sufficient to cause the emission of a droplet of ink. When a droplet of ink has to be emitted from the nozzle opening 23 in the i^{th} row 35 and the j^{th} column 37, the central control element 51 sends a signal to the switching means 49 causing the switching means to connect the first voltage generator means 47a to the i^{th} first terminal 39 and the second voltage generator means 47b to the j^{th} second terminal 41. Then the central control element 51 activates the first and second voltage generator means 47a and 47b so that they generate a first and a second voltage pulse, respectively. As a result, all first electrodes 9 in the i^{th} row 35 receive a first voltage pulse and all second electrodes 11 in the j^{th} column 37 receive a second voltage pulse. Because each one of these voltage pulses does not result in the emission of a droplet of ink, only the nozzle opening 23 at the intersection of the i^{th} row 35 and the j^{th} column 37, where the actuator element 7 is subjected to the combined effect of the first and second voltage pulses, will emit a droplet of ink. Consequently, it is possible to address each one of the nm pressure chambers 13 individually via the reduced number of n + m terminals 39, 41.

There are various combinations of first and second voltage pulses that will produce the effects discussed above. Figure 4 shows a first example. Figure 4A is a diagram showing a first voltage pulse V_i and a second voltage pulse V_j as a function of the time t and Figure 4B is a diagram showing the resulting voltage between the first and second electrodes 9, 11 of the actuator element 7 associated with the nozzle opening 23 having the position i,j in the matrix. In Figure 4A the first voltage pulse V_i is shown to be positive with respect to a fixed reference potential 0 (for example ground) and the second voltage pulse V_j is shown to be negative with respect to this reference potential. In this example, the first and second voltage pulses V_i and V_j have substantially the same shape. They start at a time t_0 and rise to a maximum value $+V_m$ for the first pulse and $-V_m$ for the second pulse. For both pulses, these maxima are reached at a time t_1, the time interval $t_1 - t_0$ being the rise time of each pulse. From the maximum value the pulses decay to 0, the latter value being reached at a time t_2. The time interval $t_2 - t_1$ is the decay time of each pulse. It can be seen from Figure 4A that the rise time is significantly longer than the decay time. During the rise time, the first electrode 9 gradually becomes more positive with respect to ground and the second electrode 11 gradually becomes more negative. During the decay time, both electrodes rapidly return to ground potential. The result is shown in the diagram of Figure 4B. During the interval $t_1 - t_0$ the voltage between the electrodes 9, 11 slowly rises to a maximum value $2V_m$ causing the pressure chamber 13 to expand slowly, thereby being filled with ink. During the interval $t_2 - t_1$ the voltage between the electrodes 9, 11 rapidly drops to 0 and the pressure chamber 13 rapidly contracts so that a droplet of ink is ejected from the nozzle opening 23. It is to be noted that each one of the first and second voltage pulses V_i and V_j separately causes an expansion and a subsequent contraction of the pressure chamber 13 that is insufficient for the ejection of a droplet of ink.

Figures 5A and 5B are similar to Figures 4A and 4B. They show a second example of a suitable combination of first and second voltage pulses. In this example the first voltage pulse V_i is negative with respect to the reference potential (e.g. ground) and the second voltage pulse V_j is positive. As in the first example, the maxima $-V_m$ and $+V_m$ of the first and second voltage pulses substantially coincide at a time t_1. In this example the rise time $t_1 - t_0$ of the two voltage pulses is relatively short, the decay time $t_2 - t_1$ being relatively long. The result is that the potential difference $V_i - V_j$ between the first and second electrodes 9, 11 is negative. Figure 5B shows $V_j - V_i$ which is, of course, positive. It can be seen that $V_j - V_i$ rapidly rises to a maximum value $2V_m$ and then slowly decays to zero. The result is that the pressure chamber 13 rapidly contracts so that a droplet of ink is ejected and then slowly expands so that it is filled again with ink.

In the first and second examples the maximum values V_m of the first and second voltage pulses are substantially equal, be it that one of them is positive and the other one negative. This is preferred because it is the most simple manner to ensure that only the combined effect of the first and second voltage pulses can cause the ejection of a droplet of ink. Nevertheless, it is very well possible to allow differences in the maximum values of the first and second voltage pulses. It is also possible for the voltage to stay at the maximum value for a predetermined time interval before the decay starts.

Figure 6 shows a third example of a suitable combination of first and second voltage pulses. As in the previous examples, Figure 6A shows the first and second voltage pulses individually as a function of time t and Figure 6B shows the resulting potential difference between the first and second electrodes 9, 11. In this example the first and second voltage pulses V_i and V_j are positive with respect to a fixed reference potential 0 (e.g. ground). The first voltage pulse V_i starts at the time t_0 and reaches a maximum value V_{im} at the time t_1. Then it decays to 0, this value being reached at the time t_2. The second voltage pulse V_j starts at the time t_1 and reaches a maximum value V_{jm} at the time t_2. Then it decays to 0, this value being reached at the time t_3. The rise time $t_1 - t_0$ of the first pulse V_i is significantly longer than its decay time $t_2 - t_1$ and the rise time $t_2 - t_1$ of the second pulse V_j is significantly shorter than its decay time $t_3 - t_2$. The decay time of the first pulse V_i and the rise time of the second pulse V_j substantially coincide in the time interval $t_2 - t_1$. The resulting potential difference $V_i - V_j$ between the first and second electrodes 9, 11 is shown in the diagram of Figure 6B. In the time interval $t_1 - t_0$ the first electrode 9 slowly becomes more positive with respect to the second electrode 11. After reaching a first maximum value V_{im} the potential difference rapidly drops to zero and then rapidly becomes negative. This process is completed at the time t_2 when a (negative) second maximum value $-V_{jm}$ has been reached. Finally, the potential difference slowly returns to zero. As a result, the pressure chamber 13 slowly expands in the time interval $t_1 - t_0$, then rapidly contracts in the time interval $t_2 - t_1$, the minimum volume during this contraction being smaller than the volume at rest because at the time t_2 the second electrode 11 is negative with respect to the first electrode 9. This rapid contraction from a maximum volume exceeding the volume at rest to a minimum volume smaller than the volume at rest is sufficient to cause the ejection of a droplet of ink. Neither the contraction from the maximum volume to the volume at rest (which would be caused by the first voltage pulse alone) nor the contraction from the volume at rest to the minimum volume (which would be caused by the second voltage pulse alone) would be sufficient for the ejection of a droplet of ink.

Figure 7 is a diagram similar to the diagram of Figure 6A showing a fourth example of a suitable combination of first and second voltage pulses. In this example the first and second voltage pulses are negative with respect to ground (zero potential). The second voltage pulse V_j rises from 0 to a maximum value $-V_{jm}$ in a relatively long rise time $t_1 - t_0$ and decays to 0 in a relatively short decay time $t_2 - t_1$. The first voltage pulse V_i rises from 0 to a maximum value $-V_{im}$ in a relatively short rise time $t_2 - t_1$ and decays to 0 in a relatively long decay time $t_3 - t_2$. The decay time of the second pulse and the rise time of the first pulse substantially coincide. It can be seen easily that the resulting potential difference between the first and second electrodes 9, 11 is the same as in the third example. This is the potential difference shown in Figure 6B.

In the examples shown in Figures 6 and 7 the maximum values and the durations of the first and second voltage pulses have been chosen arbitrarily within the limits imposed by the condition that a combination of the two pulses is necessary for the ejection of a droplet of ink. Sometimes it may be advantageous to impose a further condition in order to prevent detrimental electrochemical processes. As explained in relation to Figure 2, the actuator plate 7 consists of layers of a piezoelectric ceramic material alternated with electrode layers, the odd-numbered electrode layers being connected to the first electrode 9 and the even-numbered electrode layers being connected to the second electrode 11. The electrode layers are interrupted by the recess that forms the pressure chamber 13 and, consequently, their edges form part of the side walls of this pressure chamber (to the left and right in Figure 2). As a result of this, the electrode layers are exposed to the interior of the pressure chamber 13 and to the ink that is present in the pressure chamber during operation of the ink jet recording device. This ink may be electrically conductive, for example if a water-based ink is used. Because the odd-numbered electrode layers are connected to the first electrode 9 and the even-numbered electrode layers to the second electrode 11 and because in operation a voltage is applied between the first and second electrodes, electrochemical processes may take place in the system comprising the electrode layers and the ink. Such processes could easily damage the electrode layers. The electrochemical processes and, consequently, the damage can be prevented to a large extent by an appropriate choice of the potential difference between the first and second electrodes 9, 11 as a function of time. It has been found that the electrochemical processes are substantially prevented if the potential difference $V_i - V_j = U(t)$ is chosen such that $\int U(t)dt = 0$ where t is the time. This is, of course, possible only if U(t) has a positive and a negative part as in Figure 6B. The condition is satisfied if the surface defined by the positive part is equal to the surface defined by the negative part. Figure 8 shows an example of a curve representing U(t) in which the surface 53 defined by the positive part 55 is substantially equal to the surface 57 defined by the negative part 59. A curve of this type can be obtained by choosing the first and second voltage pulses such that they have the same polarity (as in the third and fourth examples) and that the surfaces they define are equal. It is not necessary for the first and second voltage pulses to have the same shape.

CLAIMS:

1. An ink jet recording device including a recording head (1) comprising: a plurality of pressure chambers (13), each pressure chamber communicating with an ink reservoir (29) and with a nozzle opening (23), the nozzle openings being formed as through holes in a nozzle plate (19) that covers the pressure chambers so as to form a wall of each pressure chamber, said nozzle openings being arranged in a matrix comprising n rows (35) and m columns (37);
a number of piezoelectric actuator elements (7) corresponding to the number of pressure chambers, each actuator element comprising a first electrode (9) and a second electrode (11), each actuator element being arranged in cooperative relationship with one of the pressure chambers such that the volume of the pressure chamber is changed when a voltage is applied between the first and second electrodes, the pressure chamber expanding when the first electrode is made positive with respect to the second electrode and contracting when the first electrode is made negative with respect to the second electrode, a droplet of ink being emitted from the nozzle opening if a contraction of the pressure chamber causes a relative decrease in its volume that exceeds a predetermined value;
the recording device further including a control unit (5) for selectively applying predetermined voltage pulses to the first and second electrodes of each actuator element, characterized in that the recording head comprises n first terminals (39) and m second terminals (41), the first electrodes (9) of the actuator elements (7) associated with the pressure chambers (13) that have nozzle openings (23) in a common row (35) being electrically connected to one of the first terminals and the second electrodes (11) of the actuator elements associated with the pressure chambers that have nozzle openings in a common column (37) being electrically connected to one of the second terminals, the control unit (5) being arranged to selectively provide first voltage pulses (V_i) to the first terminals and to selectively provide second voltage pulses (V_j) to the second terminals, each voltage pulse having a rise time, a maximum value and a decay time, the voltage pulses being chosen such that the change in volume of a pressure chamber caused by either a first or a second voltage pulse is insufficient to cause the emission of a droplet of ink, whereas the change in volume caused by the combined effect of a first and a second voltage pulse is sufficient to

cause the emission of a droplet of ink.

2. An ink jet recording device as claimed in Claim 1, characterized in that the first voltage pulses (V_i) are positive with respect to a fixed reference potential and the second voltage pulses (V_j) are negative with respect to the reference potential, each voltage pulse having a relatively long rise time and a relatively short decay time, the maxima of the first and second voltage pulses being substantially coincident in time.

3. An ink jet recording device as claimed in Claim 1, characterized in that the first voltage pulses (V_i) are negative with respect to a fixed reference potential and the second voltage pulses (V_j) are positive with respect to the reference potential, each voltage pulse having a relatively short rise time and a relatively long decay time, the maxima of the first and second voltage pulses being substantially coincident in time.

4. An ink jet recording device as claimed in Claim 3 or 4, characterized in that the maximum values (V_m) of the first and second voltage pulses (V_i,V_j) are substantially equal.

5. An ink jet recording device as claimed in Claim 1, characterized in that the first and second voltage pulses (V_i,V_j) are positive with respect to a fixed reference potential, the first voltage pulse having a relatively long rise time and a relatively short decay time, the second voltage pulse having a relatively short rise time and a relatively long decay time, the decay time of the first voltage pulse and the rise time of the second voltage pulse substantially coinciding.

6. An ink jet recording device as claimed in Claim 1, characterized in that the first and second voltage pulses (V_i,V_j) are negative with respect to a fixed reference potential, the second voltage pulse having a relatively long rise time and a relatively short decay time, the first voltage pulse having a relatively short rise time and a relatively long decay time, the decay time of the second voltage pulse and the rise time of the first voltage pulse substantially coinciding.

7. An ink jet recording device as claimed in Claim 5 or 6, characterized in that the first and second voltage pulses (V_i,V_j) are chosen such that the potential difference U(t) between the first and second electrodes (9,11) of an actuator element (7) that receives first and second voltage pulses substantially satisfies the relation $\int U(t)dt = 0$ where t is the time.

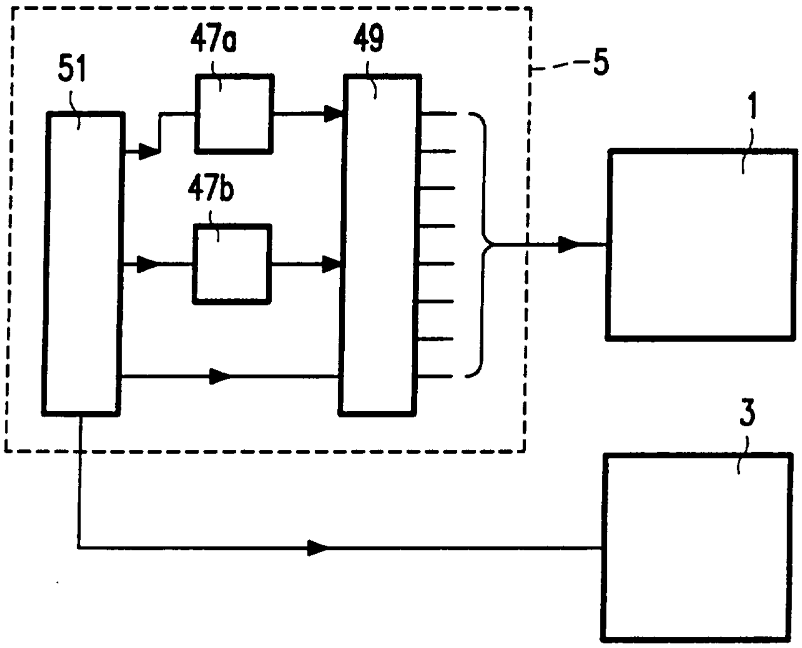

FIG. 1

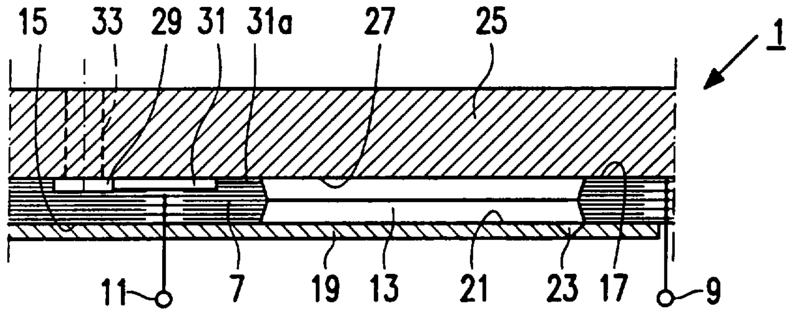

FIG. 2

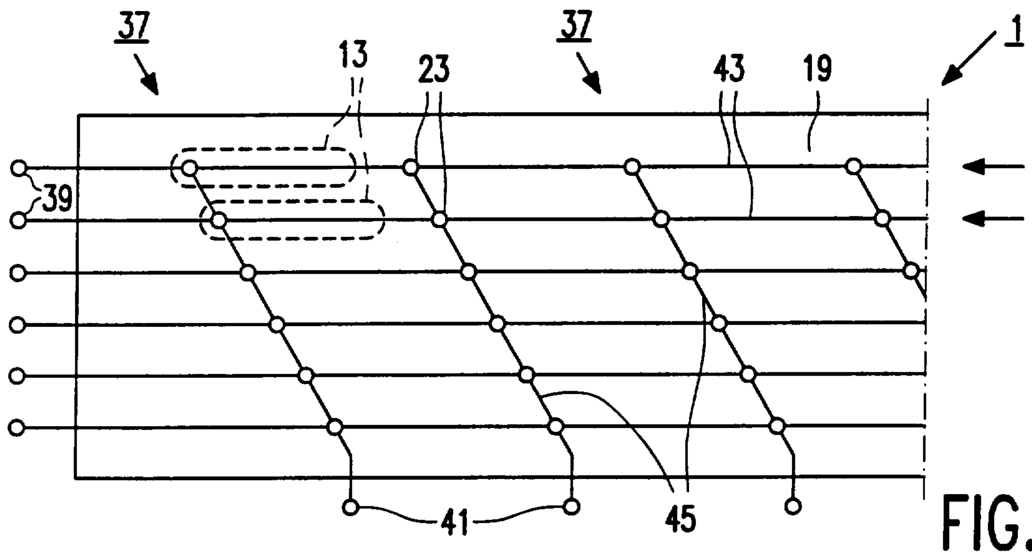

FIG. 3

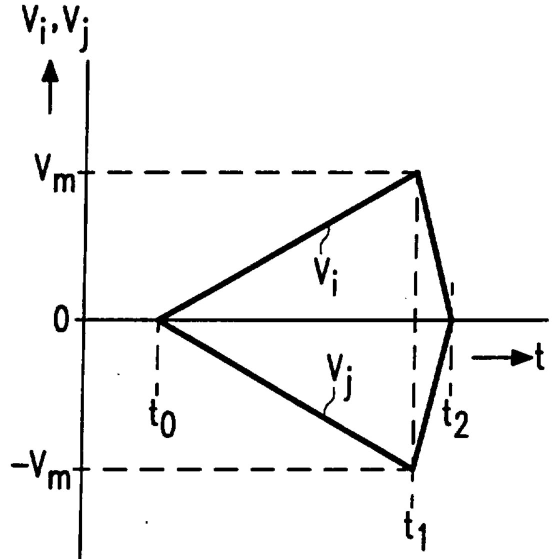

FIG. 4A

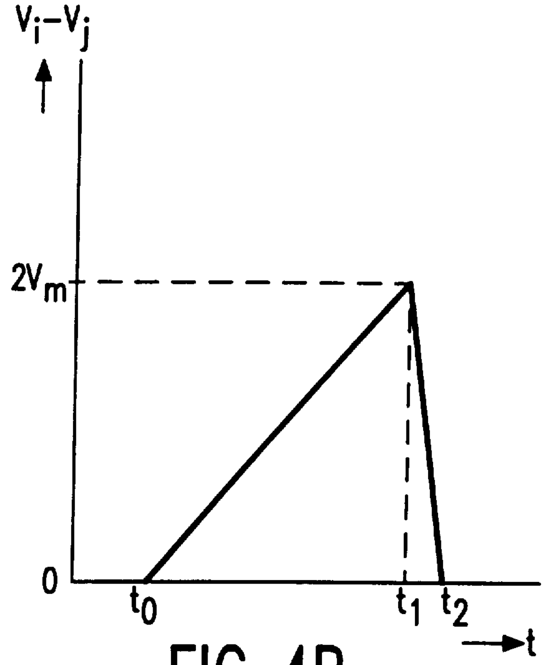

FIG. 4B

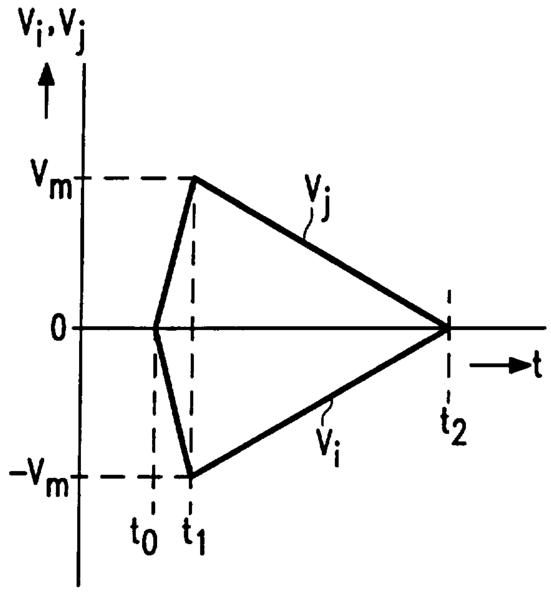

FIG. 5A

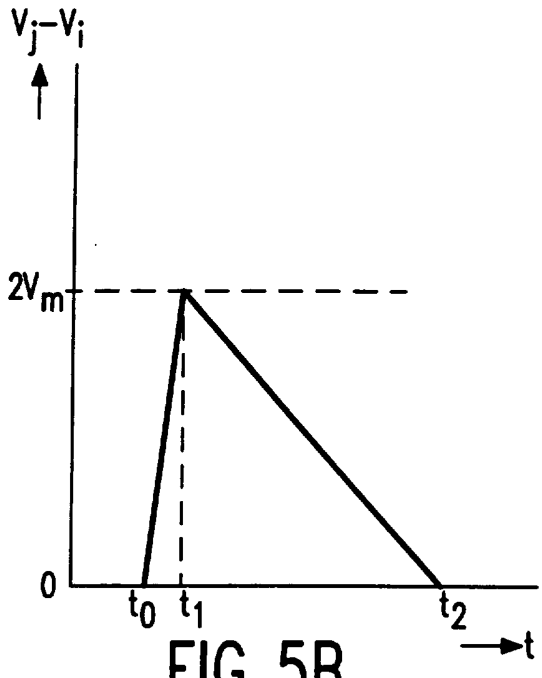

FIG. 5B

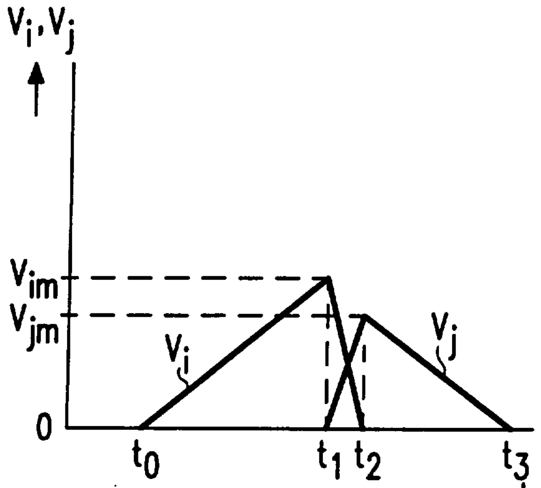

FIG. 6A

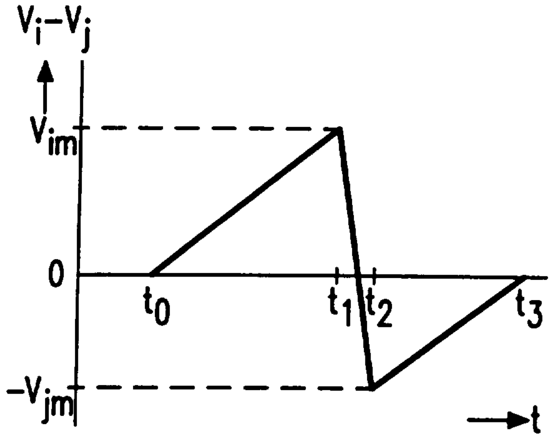

FIG. 6B

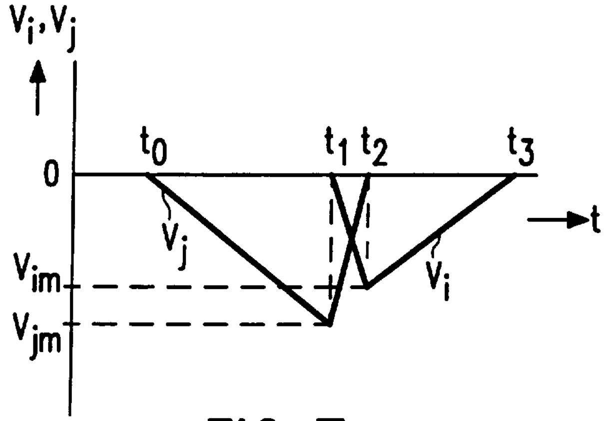

FIG. 7

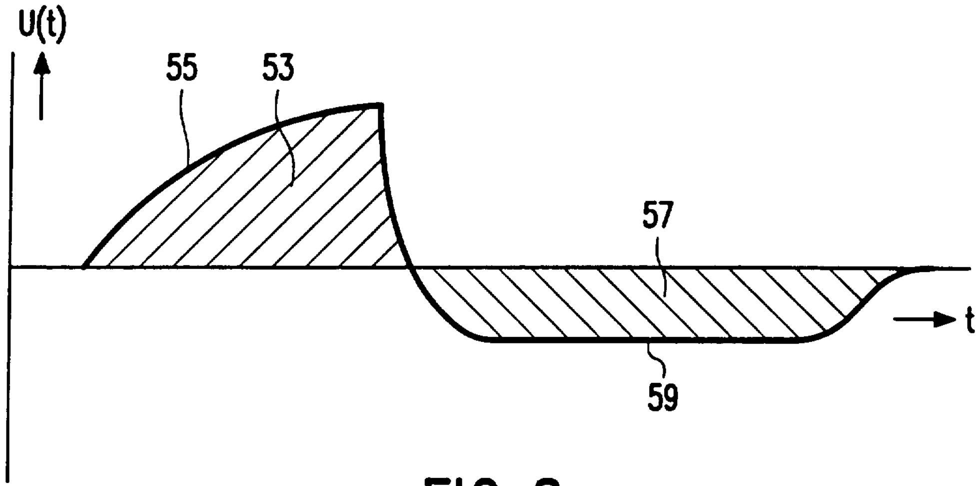

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 95/00917

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: B41J 2/045
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: B41J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0516188 A1 (SEIKO EPSON CORPORATION), 2 December 1992 (02.12.92) --	1-7
A	EP 0443628 A2 (SEIKO EPSON CORPORATION), 28 August 1991 (28.08.91) --	1-7
A	US 5359350 A (NAKANO ET AL), 25 October 1994 (25.10.94) --	1-7
A	US 5264865 A (SHIMODA ET AL), 23 November 1993 (23.11.93) -- --------	1-7

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 February 1996	20.02.96

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Per-Olof Warnbo Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Information on patent family members

05/02/96

International application No.
PCT/IB 95/00917

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		EP-A- 0655334	31/05/95
		EP-A- 0678384	25/10/95
		JP-A- 4001052	06/01/92
		US-A- 5444471	22/08/95
		US-A- 5446485	29/08/95
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		EP-A- 0678384	25/10/95
		JP-A- 4001052	06/01/92
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		JP-A- 63153149	25/06/88