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(72) Inventors:
• **SHIMOMURA Akito**
Tokyo 100-7015 (JP)
• **KOBAYASHI Ryohei**
Tokyo 100-7015 (JP)
• **KIZAWA Akiko**
Tokyo 100-7015 (JP)

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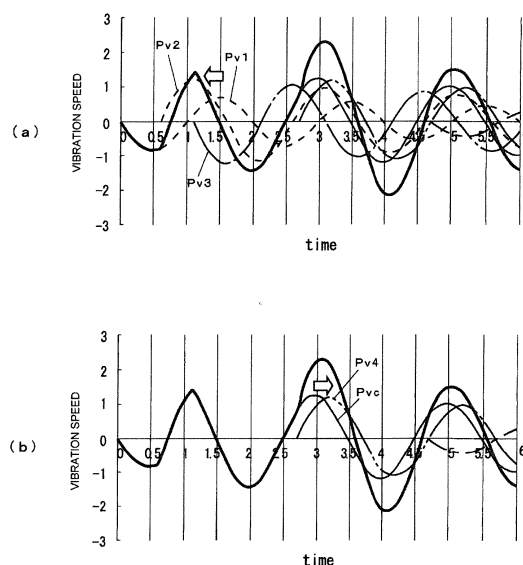
(74) Representative: **Henkel, Breuer & Partner**
Patentanwälte
Maximiliansplatz 21
80333 München (DE)

(71) Applicant: **Konica Minolta, Inc.**
Tokyo 100-7015 (JP)

(54) **INKJET PRINTING APPARATUS, INKJET HEAD DRIVING METHOD, AND DRIVING WAVEFORM-DESIGNING METHOD**

(57) The present invention addresses the problem of making it possible to drive a head in a multi-drop mode using a driving waveform that is highly robust with respect to AL value and form high quality images. Said problem is solved by: the driving waveform having multiple driving pulses for varying the volume of the pressure chamber multiple times; the driving pulse for discharging the first droplet varying the volume of the pressure chamber and inducing two or more overlapping pressure waves inside the pressure chamber, and there being a phase shift of -0.6 AL to 0.6 AL between the pressure wave oscillation induced in the pressure chamber when the first droplet is discharged and the pressure wave oscillation induced in the pressure chamber by the action prior thereto; and the driving pulse for discharging the subsequent second droplet varying the volume of the pressure chamber and inducing two or more overlapping pressure waves in the pressure chamber, and there being, between the pressure wave oscillation induced in the pressure chamber when the second droplet is discharged and a composite oscillation of the pressure wave oscillation induced in the pressure chamber by the action prior thereto and the reverberation pressure wave oscillation remaining in the pressure chamber as a result of discharging the first droplet, a phase shift in the direction opposite to the phase shift when the first droplet is discharged.

FIG. 8



Description

TECHNICAL FIELD

[0001] The present invention relates to an inkjet recording apparatus, a method for driving an inkjet head, and a method for designing a driving waveform, and more particularly to an inkjet recording apparatus, a method for driving an inkjet head, and a method for designing a driving waveform which can drive the inkjet head in a multidrop system with the use of a driving waveform having high robustness to each AL value and can form high-quality images.

BACKGROUND ART

[0002] In recent years, to form inkjet images having excellent gradation properties, a need for multidrop to properly discharge different liquid amounts of droplets from one inkjet has increased.

[0003] As a method for properly discharging different liquid amounts of droplets from the same nozzle, there is known a method for repeatedly applying the same driving pulse in one pixel period to continuously discharge a plurality of droplets from the same nozzle and impacting them within the same pixel on a recording medium (Patent Document 1). A dot diameter of one pixel can be changed by varying the number of times of applying the driving pulse. However, this method has a problem that a driving period is prolonged as the dot diameter of one pixel is increased.

[0004] On the other hand, the present applicant has suggested a driving waveform in the multidrop system which has respective driving pulses, i.e., a first expansion pulse to expand a capacity of a pressure chamber for a fixed time, a first contraction pulse to contract the capacity of the pressure chamber for a fixed time, a second expansion pulse to expand the capacity of the pressure chamber for a fixed time, and a second contraction pulse to contract the capacity of the pressure chamber for a fixed time in the mentioned order (Patent Document 2).

[0005] When the driving pulses of this driving waveform are applied to a pressure generator of the inkjet head, the capacity of the pressure chamber fluctuates more than once, and two or more droplets are thereby continuously discharged from the same nozzle. Further, when the respective droplets are combined during flight and or impacted within the same pixel on the recording medium, the dot diameter of one pixel can be increased without prolonging the driving period.

CITATION LIST

PATENT DOCUMENTS

[0006]

Patent Document 1: JP2000-15803A

Patent Document 2: WO2015/152185

Patent Document 3: JP2001-328259A

DISCLOSURE OF INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0007] The present inventors have conducted further examinations on the driving waveform in the multidrop system, and found out the following new problem.

[0008] A pulse width of each driving pulse in the driving waveform is set based on an acoustic resonant period of a pressure wave inherent to the pressure chamber of the inkjet head in such a manner that discharge characteristics such as a liquid amount or a droplet speed can become intended characteristics. Assuming that 1/2 of this acoustic resonant period is AL, the pulse width which determines the discharge characteristics is defined by an AL value.

[0009] However, in general, the inkjet head has a given level of variation in a pressure chamber shape due to a manufacturing method, a material, and others. Thus, the AL value also has a variation in accordance with, e.g., each pressure chamber, each nozzle row, or each inkjet head. Thus, even if the pulse widths are uniformly set for the purpose of realizing the intended discharge characteristics, the discharge characteristics vary depending on a variation in AL value in accordance with each pressure chamber, each nozzle row, each inkjet head, or the like in some cases. This variation in discharge characteristics is apt to cause a deviation in impact position of each droplet and becomes a factor which distorts images as a distance (a gap) between a nozzle surface and the recording medium increases, namely, as a flying distance of droplets increases. In case of a printing apparatus which forms inkjet images on cloth in particular, since the gap becomes larger than that in a general recording apparatus, an influence of the variation in discharge characteristics due to the variation in AL value is considerable.

[0010] FIG. 15 is a view comparing a case where a general driving pulse to discharge one droplet from each nozzle is applied so that one droplet (a small droplet: 7 pl) is discharged from each nozzle and impacted by using an inkjet head with a case where a driving pulse in the multidrop system described in Patent literature 2 and the general driving pulse are continuously applied so that a droplet (a medium droplet: 18 pl) is discharged from each nozzle and impacted by using the same inkjet head. The gap is 3 mm.

[0011] In this case, a voltage value of the driving pulse applied to the inkjet head is adjusted in such a manner that impact positions of the small droplets are aligned in a row. Thus, the impact positions of the small droplets hardly deviate as a matter of course, but impact deviations of the medium droplets occur. The present inventor has conducted the earnest examination on the cause, and revealed that the driving pulse in the multidrop system is unstable to a variation in AL value, and a variation

in discharge characteristics is apt to occur.

[0012] In general, an impact position deviation of the medium droplet can be adjusted by using a voltage value of the driving pulse of the medium droplet. However, since the inkjet head is used for the small droplets and medium droplets in common, a fixed voltage values must be set irrespective of sizes of the droplets. Thus, the driving pulse of the multidrop system must have high robustness which can suppress a variation in discharge characteristics even if an AL value varies in accordance with, e.g., each pressure chamber, each nozzle row, or each inkjet head.

[0013] Here, the robustness of the driving waveform will now be described. FIG. 16 to FIG. 18 are explanatory drawings illustrating the robustness to each AL value. (a) in each drawing is a view showing an example of a driving waveform which has an expansion pulse to expand a capacity of the pressure chamber of the inkjet head and a contraction pulse to contract the capacity of the pressure chamber and discharges one droplet from the nozzle, (b) in the same is a graph showing a change in droplet speed to a variation in AL value, and (c) in the same is a graph showing a vibration speed of a meniscus in the nozzle provided by the driving waveform. The vibration of the meniscus is positive (a direction protruding toward the outside of the nozzle) when a positive pressure wave is generated in the pressure chamber, and it is negative (a direction retracting toward the inside of the nozzle) when a negative pressure wave is generated in the same.

[0014] Each of the driving waveforms enables discharge of one droplet from the nozzle by falling of the contraction pulse synchronized with falling of the expansion pulse. As shown in FIG. 16, when a pulse width of this contraction pulse is set to 1.0 AL, a phase of a pressure wave vibration excited in the pressure chamber with a rising pulse P10 of the expansion pulse coincides with a phase of a pressure wave vibration excited in the pressure chamber with a falling pulse P20. Thus, a discharge pressure can be efficiently imparted to a liquid in the pressure chamber by a combined vibration of the respective pressure wave vibrations. In this case, since peaks of the respective pressure wave vibrations coincide with each other, even if the phases of the respective pressure wave vibrations are shifted due to a variation in AL value, a change in combined vibration caused due to this shift is small. Thus, the graph showing a change in droplet speed stays flat. That is, since the change in droplet speed to each AL value is very obtuse, the robustness to a variation in AL value is high. It is to be noted that P30 denotes a rising pulse of the contraction pulse.

[0015] On the other hand, as shown in FIG. 17 and FIG. 18, when the pulse width of the expansion pulse to discharge a droplet is set to 0.5 AL or 1.5 AL, the phase of the pressure wave vibration excited in the pressure chamber with the rising pulse P10 of the expansion pulse does not coincide with the phase of the pressure wave vibration excited in the pressure chamber with the falling pulse P20. The phase of the pressure wave vibration

produced with the falling pulse P20 of the expansion pulse advances (a left direction) in FIG. 17 or delays (a right direction) in FIG. 18 with respect to the phase of the pressure wave vibration produced with the rising pulse P10 of the expansion pulse. Consequently, a change in combined vibration due to a variation in AL value increases, and the graph of the change in droplet speed does not stay flat. In FIG. 17, a declining graph is provided, and a speed fluctuation has a negative correlation. Further, in FIG. 18, a soaring graph is provided, and a speed fluctuation has a positive correlation. In both the cases, a change in droplet speed to the AL value is sensitive, and hence the robustness to a variation in AL value decreases.

[0016] As described above, when the pulse width of the expansion pulse to discharge a droplet is set to 1.0 AL, the driving waveform with the high robustness to each AL value can be provided. However, this corresponds to a case where one droplet is discharged from the nozzle. In case of such a driving waveform of the multidrop system as described in Patent Document 2, since the capacity of the pressure chamber is fluctuated more than once, overlap of pressure wave vibrations excited in the pressure chamber becomes more complicated. Furthermore, in the multidrop system, since a plurality of droplets form one pixel, the expansion pulse is not necessarily set to 1.0 AL as different from the example where only one droplet is discharged. Thus, enabling driving in the multidrop system with the driving waveform having the high robustness to each AL value is desired even when the pulse width of the expansion pulse to discharge each droplet is not 1 AL.

[0017] It is to be noted Patent Document 3 discloses matching phases of pressure wave vibrations produced at respective nodes of a driving waveform, and very small droplets of 20 μm are discharged, and the driving waveform of the multidrop system having the high robustness to each AL value is not disclosed.

[0018] Thus, the present invention addresses a problem of providing an inkjet recording apparatus which can drive an inkjet head in a multidrop system by using a driving waveform having high robustness to each AL value and form high-quality images.

[0019] Further, the present invention addresses another problem of providing a method for driving an inkjet head by which the inkjet head can be driven in a multidrop system by using a driving waveform having high robustness to each AL value and high-quality images can be formed.

[0020] Furthermore, the present invention addresses still another problem of providing a method for designing a driving waveform by which the driving waveform of a multidrop system having high robustness to each AL value can be designed.

[0021] Other problems of the present invention will become clear from the following description.

MEANS FOR SOLVING PROBLEM

[0022] The problems can be solved by each of the following inventions.

[0023]

1. An inkjet recording apparatus comprising:

an inkjet head which fluctuates a capacity of a pressure chamber by driving a pressure generator based on application of a driving waveform, imparts a pressure for discharge to a liquid in the pressure chamber, and discharges a droplet from a nozzle; and

a driving control unit which outputs the driving waveform to the pressure generator, wherein the driving control unit outputs the driving waveform having a plurality of driving pulses to discharge the plurality of droplets from the nozzle by fluctuating the capacity of the pressure chamber more than once and to combine the droplets with each other during flight or impact the droplets within the same pixel on a recording medium,

at least one driving pulse to discharge the first droplet in the plurality of droplets fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the first droplet and a pressure wave vibration excited in the pressure chamber by a prior operation have a phase shift which is -0.6 AL or more and 0.6 AL or less where AL is 1/2 of an acoustic resonant period of a pressure wave in the pressure chamber, and

at least one driving pulse to discharge the subsequent second droplet fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the second droplet and a combined vibration of a pressure wave vibration excited in the pressure chamber by a prior operation and a reverberant pressure wave vibration remaining in the pressure chamber by the discharge of the first droplet have a phase shift in a direction opposite to the phase shift in the discharge of the first droplet.

2. The inkjet recording apparatus according to said 1, wherein the driving waveform has a first expansion pulse which expands the capacity of the pressure chamber for a fixed time and a first contraction pulse which is applied in synchronization with end of application of the first expansion pulse and contracts the capacity of the pressure chamber for a fixed time

as the driving pulses to discharge the first droplet, a pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, or 1.2 AL or more and 1.6 AL or less, and

a pulse width of the first contraction pulse is 0.5 AL.

3. The inkjet recording apparatus according to said 2, wherein the driving waveform has a second expansion pulse which expands the capacity of the pressure chamber for a fixed time as the driving pulse to discharge the second droplet, and

a phase shift between a combined vibration of a pressure wave vibration excited in the pressure chamber by rising of the second expansion pulse and the reverberant pressure wave vibration remaining in the pressure chamber by the discharge of the first droplet and a pressure wave vibration excited in the pressure chamber by falling of the second expansion pulse is 0 AL or more and 1.5 AL or less when the pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, or -0.5 AL or more and 0 AL or less when the pulse width of the first expansion pulse is 1.2 AL or more and 1.6 AL or less.

4. The inkjet recording apparatus according to said 3, wherein the pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, and the pulse width of the second expansion pulse is larger than 1.2 AL and is 1.9 AL or less.

5. The inkjet recording apparatus according to said 3, wherein the pulse width of the first expansion pulse is 1.2 AL or more and 1.6 AL or less, and the pulse width of the second expansion pulse is 0.8 AL or more and 1.1 AL or less.

6. The inkjet recording apparatus according to said 3, 4, or 5, wherein the driving waveform has a second contraction pulse which contracts the capacity of the pressure chamber for a fixed time and cancels the reverberant pressure vibration remaining in the pressure chamber after the second expansion pulse.

7. The inkjet recording apparatus according to said 6, wherein the second contraction pulse is applied in synchronization with end of application of the second expansion pulse, and has a pulse width of 2 AL.

8. The inkjet recording apparatus according to said 6, wherein the second contraction pulse is applied after a pause time of 1 AL after end of application of the second expansion pulse, and has a pulse width of 1 AL.

9. The inkjet recording apparatus according to said 6, wherein the second contraction pulse is applied in synchronization with end of application of the second

expansion pulse, and has a pulse width of 0.5 AL, and

the driving waveform has a third contraction pulse with a pulse width of 1 AL which is applied after a pause time of 0.5 AL from end of application of the second contraction pulse to contract the capacity of the pressure chamber for a fixed time.

10. The inkjet recording apparatus according to any one of said 1 to 9, wherein the driving waveform is a rectangular wave.

11. The inkjet recording apparatus according to any one of said 1 to 10, wherein the inkjet head is a shear-mode type inkjet head in which the pressure generator is driven in a shear mode.

12. A method for driving an inkjet head, comprising: fluctuating a capacity of a pressure chamber more than once by applying a driving waveform to drive a pressure generator in an inkjet head; imparting a pressure for discharge to a liquid in the pressure chamber; discharging a plurality of droplets from a nozzle; and combining the droplets with each other during flight or impacting the droplets within the same pixel on a recording medium,

wherein a plurality of driving pulses configured to discharge the plurality of droplets from the nozzle by fluctuating the capacity of the pressure chamber more than once are used as the driving waveform, at least one driving pulse to discharge the first droplet in the plurality of droplets fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the first droplet and a pressure wave vibration excited in the pressure chamber by a prior operation have a phase shift which is -0.6 AL or more and 0.6 AL or less where AL is 1/2 of an acoustic resonant period of a pressure wave in the pressure chamber, and

at least one driving pulse to discharge the subsequent second droplet fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the second droplet and a combined vibration of a pressure wave vibration excited in the pressure chamber by a prior operation and a reverberant pressure wave vibration remaining in the pressure chamber by the discharge of the first droplet have a phase shift in a direction opposite to the phase shift in the discharge of the first droplet.

13. The method for driving an inkjet head according to said 12,

wherein a first expansion pulse which expands the capacity of the pressure chamber for a fixed time and a first contraction pulse which is applied in synchronization with end of application of the first expansion pulse and contracts the capacity of the pressure chamber for a fixed time are used as the driving pulses to discharge the first droplet,

a pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, or 1.2 AL or more and 1.6 AL or less, and

a pulse width of the first contraction pulse is 0.5 AL.

14. The method for driving an inkjet head according to said 13,

wherein a second expansion pulse which expands the capacity of the pressure chamber for fixed time is used as the driving pulse to discharge the second droplet, and

a phase shift between a combined vibration of a pressure wave vibration excited in the pressure chamber by rising of the second expansion pulse and the reverberant pressure wave vibration remaining in the pressure chamber by the discharge of the first droplet and a pressure wave vibration excited in the pressure chamber by falling of the second expansion pulse is 0 AL or more and 1.5 AL or less when the pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, or -0.5 AL or more and 0 AL or less when the pulse width of the first expansion pulse is 1.2 AL or more and 1.6 AL or less.

15. The apparatus for driving an inkjet head according to said 14,

wherein the pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, and the pulse width of the second expansion pulse is larger than 1.2 AL and is 1.9 AL or less.

16. The apparatus for driving an inkjet head according to said 14,

wherein the pulse width of the first expansion pulse is 1.2 AL or more and 1.6 AL or less, and the pulse width of the second expansion pulse is 0.8 AL or more and 1.1 AL or less.

17. The method for driving an inkjet head according to said 14, 15, or 16,

wherein a second contraction pulse which contracts the capacity of the pressure chamber for a fixed time and cancels the reverberant pressure vibration excited in the pressure chamber is used after the second expansion pulse as the driving waveform.

18. The method for driving an inkjet head according to said 17,

wherein the second contraction pulse is applied in synchronization with end of application of the second expansion pulse, and has a pulse width of 2 AL.

19. The method for driving an inkjet head according to said 17, wherein the second contraction pulse has a pulse width of 1 AL, and is applied after a pause time of 1 AL from end of application of the second expansion pulse.

20. The method for driving an inkjet head according to said 17, wherein the second contraction pulse has a pulse width of 0.5 AL, and is applied in synchronization with end of application of the second expansion pulse, and a third contraction pulse which contracts the capacity of the pressure chamber for a fixed time and has a pulse width of 1 AL is applied after a pause time of 0.5 AL after end of application of the second contraction pulse as the driving waveform.

21. The method for driving an inkjet head according to any one of said 12 to 20, wherein the driving waveform is a rectangular wave.

22. The method for driving an inkjet head according to any one of said 12 to 21, wherein a shear-mode type inkjet head in which the pressure generator is driven in a shear mode is used as the inkjet head.

23. A method for designing a driving waveform which has a plurality of driving pulses, comprising: driving a pressure generator by application to the pressure generator in an inkjet head; fluctuating a capacity of a pressure chamber more than once to discharge a plurality of droplets from a nozzle; and combining the droplets with each other during flight or impacting the droplets within the same pixel on a recording medium, wherein at least one driving pulse to discharge the first droplet in the plurality of droplets fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the first droplet and a pressure wave vibration excited in the pressure chamber by a prior operation have a phase shift which is -0.6 AL or more and 0.6 AL or less where AL is 1/2 of an acoustic resonant period of a pressure wave in the pressure chamber, and at least one driving pulse to discharge the subsequent second droplet fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the second droplet and a combined vibration of a pressure wave vibration excited in the pressure chamber by a prior operation and a reverberant pressure wave vibration

remaining in the pressure chamber by the discharge of the first droplet have a phase shift in a direction opposite to the phase shift in the discharge of the first droplet.

EFFECT OF THE INVENTION

[0024] According to the present invention, it is possible to provide the inkjet recording apparatus which can drive the inkjet head in the multidrop system by using the driving waveform having the high robustness to AL values and form high-quality images.

[0025] Furthermore, according to the present invention, it is possible to provide the method for driving an inkjet head by which the inkjet head can be driven in the multidrop system by using the driving waveform having the high robustness to the AL values and high-quality images can be formed.

[0026] Moreover, according to the present invention, it is possible to provide the method for designing a driving waveform by which the driving waveform in the multidrop system having the high robustness to the AL values can be designed.

BRIEF DESCRIPTION OF DRAWINGS

[0027]

FIG. 1 is a schematic block diagram showing an embodiment of an inkjet recording apparatus according to the present invention;

FIGS. 2 are views showing an embodiment of an inkjet head, where (a) is a perspective view showing an appearance with a cross section and (b) is a cross-sectional view seen from a side;

FIG. 3 is a view illustrating an embodiment of a driving waveform in a multidrop system as a driving waveform generated in a driving control unit;

FIGS. 4(a) to (c) are views illustrating an operation of the inkjet head when the driving waveform is applied;

FIG. 5 is a conceptual diagram of droplets discharged from a nozzle when the driving waveform shown in FIG. 3 is applied;

FIGS. 6 show vibration speeds of pressure wave vibrations excited in a pressure chamber when a driving waveform other than that of the present invention is applied, where (a) shows an entire state and (b) shows a state when attention is focused on a second droplet;

FIG. 7 is a graph showing a rate of speed change in droplet speed to each AL value in the driving waveform other than that of the present invention;

FIGS. 8 show vibration speeds of pressure wave vibrations excited in the pressure chamber when the driving waveform of the present invention is applied, where (a) shows an entire state and (b) shows a state when attention is focused on a second droplet;

FIG. 9 is a graph showing a rate of speed change in droplet speed to each AL value in the driving waveform of the present invention;

FIG. 10(a) is a graph showing a rate of speed change of each droplet to each AL value when a pulse width of a second expansion pulse is changed, and (b) is a graph showing a droplet amount and a droplet speed of a combined drop in this example;

FIG. 11(a) is a graph showing a rate of speed change of each droplet to each AL value when a pulse width of a first expansion pulse is changed, and (b) is a graph showing a droplet amount and a droplet speed of a combined drop in this example;

FIG. 12 is a view illustrating another embodiment of a driving waveform of the present invention;

FIG. 13 is a graph showing a rate of speed change in each droplet to each AL value provided by the driving waveform shown in FIG. 12;

FIG. 14 is a view illustrating still another embodiment of a driving waveform of the present invention;

FIG. 15 is a view illustrating a state of an impact position deviation provided by the driving waveform of a multidrop system;

FIGS. 16(a) to (c) are explanatory drawings illustrating robustness to each AL value in a driving waveform having an expansion pulse set to 1.0 AL;

FIGS. 17(a) to (c) are explanatory drawings illustrating robustness to each AL value in a driving waveform having an expansion pulse set to 0.5 AL; and

FIGS. 18(a) to (c) are explanatory drawings illustrating robustness to each AL value in a driving waveform having an expansion pulse set to 1.5 AL.

BEST MODE(S) FOR CARRYING OUT THE INVENTION

[0028] An embodiment of the present invention will now be described hereinafter with reference to the drawings.

(Inkjet Recording Apparatus)

[0029] FIG. 1 is a schematic block diagram showing an embodiment of an inkjet recording apparatus according to the present invention.

[0030] In an inkjet recording apparatus 1, a feed mechanism 2 holds a recording medium 7 formed of a paper sheet, a plastic sheet, cloth, or the like between a pair of feed rollers 22, and feeds it in a Y direction in the drawing (a sub-scanning direction) based on rotation of a feed roller 21 caused by a feed motor 23. An inkjet head (which will be simply referred to as a head hereinafter) 3 is provided between the feed roller 21 and the pair of feed rollers 22. The head 3 is mounted in a carriage 5 in such a manner that its nozzle surface side faces a recording surface 71 of the recording medium 7, and electrically connected with a driving control unit 8 through a flexible cable 6.

[0031] In the present invention, it is preferable for a distance (a gap) between the nozzle surface of the head 3 and the recording surface 71 of the recording medium 7 to be 2 mm or more, or more preferably 3 mm or more.

That is because a flying distance of each droplet increases and a variation in discharge characteristics of the droplet becomes considerably conspicuous when the gap becomes large, and hence an effect to suppress the variation in discharge characteristics can be noticeably provided by later-described application of the present invention.

[0032] The carriage 5 is provided to be reciprocable in an X-X' direction (a main scanning direction) substantially orthogonal to the sub-scanning direction along guide rails 4 provided along a width direction of the recording medium 7 by non-illustrated driver. The head 3 shown in this embodiment is a scanning type head which moves on the recording surface 71 of the recording medium 7 in the main scanning direction with reciprocating movement of the carriage 5, discharges droplets from nozzles in correspondence with image data in this movement process, and records an inkjet image. However, in the inkjet recording apparatus of the present invention, the head 3 is not restricted to the scanning type. Although not shown, the head 3 may be a line type which is formed to be long in the width direction of the recording medium 7 or has a plurality of small heads arranged in a zigzag pattern and thereby performs one-path recording on the recording medium 7 fed at a fixed speed.

[0033] FIGS. 2 are views showing an embodiment of the head 3, where (a) is a perspective view showing an appearance with a cross section and (b) is a cross-sectional view seen from a side surface.

[0034] In the head 3, many microgroove-like channels 31 and partition walls 32 are alternately juxtaposed on a substrate 30. A cover plate 33 is provided on an upper surface of the substrate 30 to close upper portions of all the channels 31. A nozzle plate 34 is joined to extend to end surfaces of the substrate 30 and the cover plate 33. One end of each channel 31 communicates with the outside through a nozzle 341 formed in this nozzle plate 34.

[0035] The other end of each channel 31 is formed to gradually become shallow to the substrate 30. A common flow path 331 which is common to the respective channels 31 is formed in the cover plate 33, and the other end of each channel 31 communicates with this common flow path 331. The common flow path 331 is closed with a plate 35. An ink supply port 351 is formed in the plate 35, and an ink is supplied to the common flow path 331 and the respective channels 31 from an ink supply tube 352 through this ink supply port 351.

[0036] The partition walls 32 are formed of a piezoelectric element such as PZT. Each partition wall 32 is formed of a piezoelectric element having an upper wall portion 321 and a lower wall portion 322 polarized in opposite directions. However, in each partition wall 32, a portion formed of the piezoelectric element may be, e.g., the upper wall portion 321 alone. Since the partition walls

32 and the channels 31 are alternately juxtaposed, one partition wall 32 is shared by the channels 31 and 31 on both sides thereof.

[0037] Driving electrodes (not shown in FIG. 2) are formed on an inner surface of each channel 31 to extend from wall surfaces to bottom surfaces of both the partition walls 32 and 32, respectively. When a driving waveform having a predetermined voltage is applied from the driving control unit 8 to the two driving electrodes arranged to interpose the partition wall 32 therebetween, the partition wall 32 undergoes shear deformation with an interface between the upper wall portion 321 and the lower wall portion 322 at the center, and a capacity of the channel 31 sandwiched between the two partition walls 32 and 32 is fluctuated. That is, the capacity of the channel 31 expands when the partition walls 32 and 32 deform to move away from each other, and the capacity of the channel 31 contracts when the partition walls 32 and 32 deform to get closer to each other. Consequently, a pressure wave is produced in the channel 31, and a pressure for discharge is imparted to the ink in the channel 31.

[0038] This head 3 is a shear-mode type head which discharges the ink in the channel 31 from the nozzle 341 by the shear deformation of the partition walls 32, and this is a preferable mode in the present invention. The shear-mode type head can efficiently discharge droplets by using a later-described rectangular wave as the driving waveform.

[0039] It is to be noted that, in this head 3, the channel 31 surrounded by the substrate 30, the partition walls 32, the cover plate 33, and the nozzle plate 34 constitutes the pressure chamber in the present invention. Further, each partition wall 32 formed of the piezoelectric element and the driving electrodes on the surface thereof constitute a pressure generator in the present invention.

[0040] The driving control unit 8 generates the driving waveform to discharge droplets from the nozzle 341. The generated driving waveform is output to the head 3, and applied to the respective driving electrodes formed on the respective partition walls 32. When a driving waveform in the multidrop system having high robustness described below is used as this driving waveform, high-quality images can be formed in the multidrop system.

(Configuration of Driving Waveform)

[0041] A configuration of the driving waveform in the multidrop system will now be described.

[0042] FIG. 3 is a view illustrating an embodiment of the driving waveform in the multidrop system as the driving waveform generated in the driving control unit 8.

[0043] A driving waveform 100 is a driving waveform to form each large droplet having a large liquid amount by discharging at least two droplets from the same nozzle 341 in the head 3 and combining them during flight. This driving waveform 100 is constituted of a plurality of driving pulses to expand and contract the capacity of the channel 31. Specifically, the driving waveform 100 has a first ex-

pansion pulse P1 which expands the capacity of the channel 31 and contracts the same after a fixed time, a first contraction pulse P2 which contracts the capacity of the channel 31 and expands the same after a fixed time, a second expansion pulse P3 which expands the capacity of the channel 31 and contracts the same after a fixed time, and a second contraction pulse P4 which contracts the capacity of the channel 31 and expands the same after a fixed time in the mentioned order.

[0044] The first expansion pulse P1 of the driving waveform 100 shown in this embodiment is a pulse which rises from a reference potential and falls to the reference potential after a fixed time (a pulse width W1). The first contract pulse P2 is a pulse which falls from the reference potential and rises to the reference potential after a fixed time (a pulse width W2). The second expansion pulse P3 is a pulse which rises from the reference potential and falls to the reference potential after a fixed time (a pulse width W3). The second contraction pulse P4 is a pulse which falls from the reference potential and rises to the reference potential after a fixed time (a pulse width W4). It is to be noted that the reference potential is 0 potential here, but it is not restricted in particular.

[0045] The first contraction pulse P2 is synchronized with falling of the first expansion pulse P1. That is, the first contraction pulse P2 continuously falls from an end of falling of the first expansion pulse P1 without a pause time. Furthermore, the second expansion pulse P3 is synchronized with rising of the first contraction pulse P2. That is, the second expansion pulse P3 continuously rises from an end of rising of the first contraction pulse P2 without a pause time. Moreover, the second contraction pulse P4 is synchronized with falling of the second expansion pulse P3. That is, the second contraction pulse P4 continuously rises from an end of falling of the second expansion pulse P3 without a pause time.

[0046] Next, an operation of the head 3 when this driving waveform 100 is applied will now be described with reference to FIG. 4. FIG. 4 shows a part of a cross section of the head 3 taken along a direction orthogonal to a length direction of each channel 31. Here, it is determined that droplets are discharged from a central channel 31B in FIG. 4. Additionally, FIG. 5 shows a conceptual drawing of droplets discharged from the nozzle when the driving waveform 100 is applied.

[0047] First, when driving electrodes 36A and 36C are earthed and the first expansion pulse P1 in the driving waveform 100 is applied to a driving electrode 36B from a neutral state of the partition walls 32B and 32C shown in FIG. 4(a), the partition walls 32B and 32C mutually deform outward as shown in FIG. 4(b), and a capacity of a channel 31B sandwiched between the partition walls 32B and 32C expands. Consequently, a negative pressure wave is generated in the channel 31B, and the ink flows in.

[0048] After a fixed time, when application of the first expansion pulse P1 is finished, the capacity of the channel 31B contracts from the expanded state, and the par-

tion walls 32B and 32C return to the neutral state shown in FIG. 4(a). After the end of application of the first expansion pulse P1, when the first contraction pulse P2 is continuously applied without a pause time, the capacity of the channel 31B enters a contracted state shown in FIG. 4(c) at once. At this time, a pressure is applied to the ink in the channel 31B, the ink is extruded from the nozzle 341, and a first droplet is discharged.

[0049] When application of the first contraction pulse P2 is finished after a fixed time, the capacity of the channel 31B expands from the contracted state, and the partition walls 32B and 32C return to the neutral state shown in FIG. 4(a). After the end of application of the first contraction pulse P2, when the second expansion pulse P3 is continuously applied without a pause time, the capacity of the channel 31B enters the expanded state shown in FIG. 4(b) at once, and a negative pressure wave is generated in the channel 31. Thus, a tail of the previously discharged first droplet is pulled, and a droplet speed is suppressed. Further, the ink again flows in due to the negative pressure wave generated in the channel 31B.

[0050] When application of the second expansion pulse P3 is finished after a fixed time, the capacity of the channel 31B contracts from the expanded state, and the partition walls 32B and 32C return to the neutral state shown in FIG. 4(a). After the end of application of the second expansion pulse P3, when the second contraction pulse P4 is continuously applied without a pause time, the capacity of the channel 31B enters the contracted state shown in FIG. 4(c) at once. At this time, a large pressure is applied to the ink in the channel 31B, the ink is further thrust after the first droplet discharged by the first expansion pulse P1 and the first contraction pulse P2, the thrust ink eventually breaks away, and a second droplet with a high speed is discharged.

[0051] As the droplets discharged with the use of this driving waveform 100, as shown in FIG. 5, following the first droplet D1 with the low droplet speed formed by the first expansion pulse P1 and the first contraction pulse P2, the second droplet D2 with the high droplet speed is formed by the second expansion pulse P3 and the second contraction pulse P4. At the beginning of discharge, the droplet D1 and the droplet D2 are continuous with each other, but the speed of the droplet D2 is sufficiently higher than that of the droplet D1, and hence these droplets are combined with each other during flight immediately after discharge to impact as one large droplet D.

[0052] When application of the second contraction pulse P4 is finished after a fixed time, the capacity of the channel 31B expands from the contracted state, and the partition walls 32B and 32C return to the neutral state in FIG. 4(a). This second contraction pulse P4 is a driving pulse configured to cancel a reverberant pressure wave vibration remaining in the channel 31B by a prior operation (application of the second expansion pulse P3 from the first expansion pulse P1). Consequently, an influence of the reverberant pressure wave vibration on a subsequent droplet discharge operation can be suppressed,

and a driving frequency can be improved. Therefore, the second contraction pulse P4 is preferably provided in the present invention.

[0053] Each of the driving pulses P1 to P4 in this driving waveform 100 is constituted of a pulse having a positive (+Von) or negative (-Voff) voltage value which expands or contracts the capacity of the channel 31 by changing a polarity. In this case, it is preferable to set the voltage values +Von of the first expansion pulse P1 and the second expansion pulse P3 and the voltage values -Voff of the first contraction pulse P2 and the second contraction pulse P4 to the same value ($|+Von| = |-Voff|$). Since the voltage values can be communalized, a circuit configuration of the driving control unit 8 can be simplified.

(Method for Designing Driving Waveform)

[0054] Next, a designing method for setting the pulse widths W1 to W4 of the respective driving pulses P1 to P4 in this driving waveform 100 will now be described.

[0055] First, prior to a description of the present invention, as an example where designing with high robustness is not performed other than the present invention, a case where pulse widths of the driving waveform 100 are set to W1=0.6 AL, W2=0.5 AL, W3=1 AL, and W4=2AL will be described.

[0056] FIGS. 6 are graphs each showing a vibration speed of a pressure wave vibration excited in the channel 31 when the driving waveform is applied. (a) shows an entire state, and (b) shows a state focusing on a second droplet. Furthermore, FIG. 7 is a graph showing a rate of speed change in droplet speed to each AL value provided by the driving waveform.

[0057] When the first contraction pulse P2 is applied after 0.6 AL from start of application of the first expansion pulse P1 and a first droplet is discharged, a phase of a pressure wave vibration Pv2 excited by falling of the first contraction pulse P2 shifts to advance from a phase of a pressure wave vibration Pv1 excited by rising (the prior operation) of the first expansion pulse P1. A rate of speed change in the first droplet to each AL value declines like FIG. 17 and has a negative correlation.

[0058] It is to be noted that, when no droplet is discharged during a driving period before this droplet discharge, this pressure wave vibration Pv1 exclusively means a pressure wave vibration excited in the channel 31 at the time of this droplet discharge. However, when a droplet is discharged in the driving period before this droplet discharge, the pressure wave vibration Pv1 means a combined vibration with a pressure wave vibration (a reverberant pressure wave vibration or the like) excited in the channel 31 by previous droplet discharge.

[0059] When the second expansion pulse P3 having a width of 1 AL is applied after 0.5 AL from the start of application of the first contraction pulse P2, timing at which this second expansion pulse P3 falls to discharge a second droplet becomes close to timing at which a combined vibration Pvc of the pressure wave vibrations Pv1

and Pv2 and a pressure wave vibration Pv3 excited by rising of the second expansion pulse P3 has the largest negative value (the highest negative pressure is formed in the channel 31). Thus, a phase of a pressure wave vibration (a second pressure wave vibration) Pv4 excited by falling of the second expansion pulse P3 shifts to advance from a phase of the combined vibration Pvc. A rate of speed change in the second droplet to each AL value in this example also declines like FIG. 17, and has a negative correlation.

[0060] Consequently, a speed of the droplet which is a combination of the first droplet and the second droplet has a declining rate of speed change as shown in FIG. 7. Therefore, the thus designed driving waveform has low robustness to a variation in AL value.

[0061] Here, when the pulse width W1 of the first expansion pulse P1 in the driving waveform 100 is fixed to a width of 0.6 AL, the robustness must be enhanced by adjusting the pulse width W3 of the second expansion pulse P3. The present inventor has paid attention to a phase shift of the pressure wave vibration excited in the channel 31 as a technique of adjusting the pulse width. As described above, a change in droplet speed to each AL value has a positive or negative correlation depending on a mode of the phase shift of the pressure wave vibration. The designed driving waveform has the negative correlation in both the first droplet and the second droplet. Thus, if the AL value varies to become smaller than a designed value, both the first and second droplet speeds become higher than a designed value, and the droplet speed of the combine drop becomes higher. Contrarily, when the AL value varies to become larger than the designed value, the droplet speed of the combine drop becomes lower. That is, it can be considered that the designed driving waveform has the lowered robustness due to enhancement of the first and second negative correlations.

[0062] Thus, according to the present invention, the pulse width W3 of the second expansion pulse P3 is configured as a pulse width having an inverse correlation (a positive correlation) which complements the first correlation (a negative correlation), thereby improving the robustness.

[0063] As an example of design with the high robustness, description will now be given as to a case where pulse widths in the driving waveform 100 are set to W1=0.6 AL, W2=0.5 AL, W3=1.6 AL, and W4=2 AL.

[0064] FIGS. 8 are graphs each showing a vibration speed of the pressure wave vibration excited in the channel 31 when the driving waveform is applied. (a) shows an entire state, and (b) shows a state focusing on the second droplet. Moreover, FIG. 9 is a graph showing a rate of speed change in droplet speed to each AL value provided by the driving waveform.

[0065] A first process to the first droplet discharge based on the first expansion pulse P1 are the same as above. Here, when the second expansion pulse P3 having a width of 1.6 AL is applied after 0.5 AL from the start

of application of the first contraction pulse P2, and timing at which this second expansion pulse P3 falls and the second droplet is discharged becomes timing in the course that the combined vibration Pvc reaches a positive peak. Thus, a phase of a pressure wave vibration (a second pressure wave vibration) Pv4 excited by falling of the second expansion pulse P3 has a phase shift in an opposite direction to the pressure wave vibration (the first pressure wave vibration) Pv2, and shifts to lag behind a phase of a combined vibration Pvc. A rate of speed change of the second droplet to each AL value soars, and has a positive correlation which is an inverse correlation of the first droplet. That is, the first droplet and the second droplet have a complementary relationship.

[0066] Consequently, a rate of speed change of a droplet which is a combination of the first droplet and the second droplet to each AL value stays substantially flat as shown in FIG. 9. Thus, the driving waveform in this case has the high robustness to a variation in AL value.

[0067] The above example corresponds to a case where W1=0.6 AL, W2=0.5 AL, and W3=1.6 AL are set, and the pulse width W3 of the second expansion pulse P3 is set to have the inverse correlation depending on the positive correlation or the negative correlation the pulse width W1 of the first expansion pulse P1 has. With this setting, the driving waveform 100 with the high robustness can be set.

[0068] In the present invention, the phase of the pressure wave vibration excited in the channel 31 at the time of discharging the first droplet does not coincide with the phase of the pressure wave vibration excited in the channel 31 by the prior operation, and a phase shift is -0.6 AL or more and 0.6 AL or less. When the phase shift deviates from this range, it is difficult to stably discharge the first droplet.

[0069] The pulse width W1 of the first expansion pulse P1 is not restricted to 0.6 AL, and the present inventor has confirmed that the same effect can be provided when this pulse width is 0.4 AL or more and 0.8 AL or less, or 1.2 AL or more and 1.6 AL or less.

[0070] Specifically, since the pulse width W1 of the first expansion pulse P1 in the driving waveform 100 determines a liquid amount of the combined droplet, in case of setting a small liquid amount, it is preferable to set W1=0.4 AL or more and 0.8 AL or less and W2=0.5 AL and, in case of setting a large liquid amount, it is preferable to set W1=1.2 AL or more and 1.6 AL or less and W2=0.5 AL.

[0071] When W1=0.4 AL or more and 0.8 AL or less and W2=0.5 are set, it is preferable to set the pulse width W3 of the second expansion pulse P3 in such a manner that the phase shift of the pressure wave vibration (the second pressure wave vibration) Pv4 produced by falling of the second expansion pulse P3 from the combined vibration Pvc becomes 0 AL or more and 1.5 AL or less. Consequently, when the liquid amount is set to be relatively small, the driving waveform with the higher robustness can be provided.

[0072] Here, FIG. 10(a) shows a rate of speed change in droplet to each AL value when the pulse width of the first expansion pulse P1 is maintained at $W1=0.6$ AL and the pulse width $W3$ of the second expansion pulse P3 is changed to 1.0 AL, 1.2 AL, 1.4 AL, 1.6 AL, 1.8 AL, and 2.0 AL. Further, 10(b) shows a droplet amount and a droplet speed of the combined drop in each case.

[0073] When the pulse width $W1$ of the first expansion pulse P1 is set to 0.6 AL, a tilt of the graph showing the rate of speed change also varies as the pulse width $W3$ of the second expansion pulse P3 changes. Here, assuming that a range of 90% to 110% of a target speed (100%) is determined to correspond to allowable values, it can be understood that the tilt of the graph stays substantially flat and falls within the allowable value range by setting the pulse width $W3$ of the second expansion pulse P3 to exceed 1.2 AL and to 1.9 AL or less. Thus, the driving waveform having the high robustness can be provided when the droplet is set to be small. In this range, the second droplet has the positive correlation to the negative correlation of the first droplet, and the first droplet and the second droplet have a complementary relationship. In this range, and the droplet amount and the droplet speed become substantially constant, and a variation in discharge characteristics can be suppressed.

[0074] Furthermore, when $W1=1.2$ AL or more and 1.6 AL or less and $W2=0.5$ are set, it is preferable to set the pulse width $W3$ of the second expansion pulse P3 in such a manner that a phase shift of the pressure wave vibration (the second pressure wave vibration) $Pv4$ produced by falling of the second expansion pulse P3 from the combined vibration Pvc becomes -0.5 AL or more and 0 AL or less. Consequently, when the liquid amount is set to become relatively large, the driving waveform having the higher robustness can be provided.

[0075] Here, FIG. 11(a) shows a rate of speed change in droplet to each AL value when the pulse width of the second expansion pulse P3 is maintained at $W3=1.0$ AL and the pulse width $W1$ of the first expansion pulse P1 is changed to 0.6 AL, 0.8 AL, 1.0 AL, 1.2 AL, 1.6 AL, and 1.8 AL. Further, 11(b) shows a droplet amount and a droplet speed of the combined drop in each case.

[0076] When the pulse width $W3$ of the second expansion pulse P3 is set to 1.0 AL, a tilt of the graph showing the rate of speed change also varies as the pulse width $W1$ of the first expansion pulse P1 changes. Here, assuming that a range of 90% to 110% ($\pm 10\%$) of a target speed (100%) is determined to correspond to allowable values, it can be understood that the tilt of the graph stays substantially flat and falls within the allowable value range by setting the pulse width $W1$ of the first expansion pulse P1 to 1.2 AL or more and 1.6 AL or less, and the driving waveform having the high robustness can be provided. In this range, the second droplet has the negative correlation to the positive correlation of the first droplet, and the first droplet and the second droplet have the complementary relationship.

[0077] Moreover, it can be understood that, in this

range, the droplet speed and the droplet amount increase as the pulse width $W1$ is raised, and the droplet amount can be set to be large.

[0078] The present inventor has confirmed that the same effect can be provided when the pulse width $W3$ of the second expansion pulse P3 is 0.8 AL or more and 1.1 AL or less without being restricted to 1.0 AL.

[0079] Meanwhile, to set the liquid amount or the droplet speed to a desired value, simply setting the pulse width $W3$ of the second expansion pulse P3 to a value which secures the robustness is not enough in some situations. In this case, as shown in FIG. 12, it is preferable to use a driving waveform 200 configured to apply the second contraction pulse P4 having $W4=1$ AL after a pause time $W5$ having a width of 1 AL from falling of the second expansion pulse P3. Consequently, a discharge pressure produced by falling of the second expansion pulse P3 can be reduced by an amount corresponding to the pause time $W5$.

[0080] Here, FIG. 13 shows a graph of a rate of speed change in droplet to each AL value when the driving waveform 200 in which $W1=0.6$ AL, $W2=0.5$ AL, $W3=1.4$ AL, $W4=1$ AL, and $W5=1$ AL are set is applied. It can be understood that the rate of speed change stays substantially flat and the robustness is improved.

[0081] It is also preferable for the driving waveform to have a configuration shown in FIG. 14. This driving waveform 300 has a third contraction pulse P5 which contracts the capacity of the channel 31 after a fixed pause time $W6$ from the end of application of the second contraction pulse P4.

[0082] The second contraction pulse P4 is synchronized with falling of the second expansion pulse P3. That is, the second contraction pulse P4 continuously falls from an end of falling of the second contraction pulse P3 without a pause time. Additionally, when the pulse width $W4$ of this second contraction pulse P4 is set to 0.5 AL and the third contraction pulse P5 having a pulse width $W7=1$ AL is provided after a pause time $W6=0.5$ AL, the reverberant pressure wave vibration in the channel 31 after discharging the second droplet can be effectively cancelled, and the droplet discharge in the multidrop system can be continuously and stably performed.

[0083] Each of the above-described driving waveforms 100, 200, and 300 is formed of a rectangular wave. In particular, since the shear-mode type head 3 can easily control a phase of the pressure wave vibration produced in the channel 31 to application of the driving waveform formed of the rectangular wave, using the rectangular wave as the driving waveform 100, 200, or 300 is preferable in the present invention. Further, since the rectangular wave can be readily formed by using a simple digital circuit, a circuit configuration can be simpler than that in a case of using a trapezoidal wave having a sloping wave. It is to be noted that the rectangular wave means a wave in which both a rising time and a falling time between 10% and 90% of a voltage are $1/2$ or less of AL or preferably $1/4$ or less of the same.

[0084] Further, each of the above-described driving waveforms 100, 200, and 300 enables continuously discharging a plurality of droplets from the same nozzle 341 and combining the plurality of droplets during flight, and the present invention can be likewise applied to a case where the droplets are allowed to impact within the same pixel on the recording medium 7.

(Method for Driving Inkjet Head)

[0085] The head 3 is driven by the driving waveform 100, 200, or 300 output from the driving control unit 8, and forms inkjet images on the recording medium 7. When the pulse width of each driving pulse in each driving waveform 100, 200, or 300 is set as described above, the driving in the multidrop system with the high robustness to each AL value can be realized, and hence high-quality images can be formed in the multidrop system.

REFERENCE SIGNS LIST

1: inkjet recording apparatus

2: feed mechanism

21: feed roller

22: pair of feed rollers

23: feed motor

3: inkjet head

30: substrate

31: channel (pressure chamber)

32: partition wall (pressure generator)

321: upper wall portion

322: lower wall portion

33: cover plate

331: common flow path

34: nozzle plate

341: nozzle

35: plate

351: ink supply port

352: ink supply tube

4: guide rail

5: carriage

6: flexible cable

7: recording medium

71: recording surface

8: driving control unit

100, 200, 300: driving waveform

D: droplet

D1: first droplet

D2: second droplet

P1: first expansion pulse

P2: first contraction pulse

P3: second expansion pulse

P4: second contraction pulse

P5: third contraction pulse

Pv1 to Pv4: pressure wave vibration

Pvc: combined vibration

W1: pulse width of the first expansion pulse

W2: pulse width of the first contraction pulse

W3: pulse width of the second expansion pulse

W4: pulse width of the second contraction pulse

W5: pause time

W6: pause time

W7: pulse width of the third contraction pulse

Claims

1. An inkjet recording apparatus comprising:

an inkjet head which fluctuates a capacity of a pressure chamber by driving a pressure generator based on application of a driving waveform, imparts a pressure for discharge to a liquid in the pressure chamber, and discharges a droplet from a nozzle; and

a driving control unit which outputs the driving waveform to the pressure generator, wherein the driving control unit outputs the driving waveform having a plurality of driving pulses to discharge the plurality of droplets from the nozzle by fluctuating the capacity of the pressure chamber more than once and to combine the droplets with each other during flight or impact the droplets within the same pixel on a recording medium,

at least one driving pulse to discharge the first droplet in the plurality of droplets fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the first droplet and a pressure wave vibration excited in the pressure chamber by a prior operation have a phase shift which is -0.6 AL or more and 0.6 AL or less where AL is 1/2 of an acoustic resonant period of a pressure wave in the pressure chamber, and

at least one driving pulse to discharge the subsequent second droplet fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited

- in the pressure chamber at the time of discharging the second droplet and a combined vibration of a pressure wave vibration excited in the pressure chamber by a prior operation and a reverberant pressure wave vibration remaining in the pressure chamber by the discharge of the first droplet have a phase shift in a direction opposite to the phase shift in the discharge of the first droplet.
2. The inkjet recording apparatus according to claim 1, wherein the driving waveform has a first expansion pulse which expands the capacity of the pressure chamber for a fixed time and a first contraction pulse which is applied in synchronization with end of application of the first expansion pulse and contracts the capacity of the pressure chamber for a fixed time as the driving pulses to discharge the first droplet, a pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, or 1.2 AL or more and 1.6 AL or less, and a pulse width of the first contraction pulse is 0.5 AL.
 3. The inkjet recording apparatus according to claim 2, wherein the driving waveform has a second expansion pulse which expands the capacity of the pressure chamber for a fixed time as the driving pulse to discharge the second droplet, and a phase shift between a combined vibration of a pressure wave vibration excited in the pressure chamber by rising of the second expansion pulse and the reverberant pressure wave vibration remaining in the pressure chamber by the discharge of the first droplet and a pressure wave vibration excited in the pressure chamber by falling of the second expansion pulse is 0 AL or more and 1.5 AL or less when the pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, or -0.5 AL or more and 0 AL or less when the pulse width of the first expansion pulse is 1.2 AL or more and 1.6 AL or less.
 4. The inkjet recording apparatus according to claim 3, wherein the pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, and the pulse width of the second expansion pulse is larger than 1.2 AL and is 1.9 AL or less.
 5. The inkjet recording apparatus according to claim 3, wherein the pulse width of the first expansion pulse is 1.2 AL or more and 1.6 AL or less, and the pulse width of the second expansion pulse is 0.8 AL or more and 1.1 AL or less.
 6. The inkjet recording apparatus according to claim 3, 4, or 5, wherein the driving waveform has a second contraction pulse which contracts the capacity of the pressure chamber for a fixed time and cancels the reverberant pressure vibration remaining in the pressure chamber after the second expansion pulse.
 7. The inkjet recording apparatus according to claim 6, wherein the second contraction pulse is applied in synchronization with end of application of the second expansion pulse, and has a pulse width of 2 AL.
 8. The inkjet recording apparatus according to claim 6, wherein the second contraction pulse is applied after a pause time of 1 AL after end of application of the second expansion pulse, and has a pulse width of 1 AL.
 9. The inkjet recording apparatus according to claim 6, wherein the second contraction pulse is applied in synchronization with end of application of the second expansion pulse, and has a pulse width of 0.5 AL, and the driving waveform has a third contraction pulse with a pulse width of 1 AL which is applied after a pause time of 0.5 AL from end of application of the second contraction pulse to contract the capacity of the pressure chamber for a fixed time.
 10. The inkjet recording apparatus according to any one of claims 1 to 9, wherein the driving waveform is a rectangular wave.
 11. The inkjet recording apparatus according to any one of claims 1 to 10, wherein the inkjet head is a shear-mode type inkjet head in which the pressure generator is driven in a shear mode.
 12. A method for driving an inkjet head, comprising: fluctuating a capacity of a pressure chamber more than once by applying a driving waveform to drive a pressure generator in an inkjet head; imparting a pressure for discharge to a liquid in the pressure chamber; discharging a plurality of droplets from a nozzle; and combining the droplets with each other during flight or impacting the droplets within the same pixel on a recording medium, wherein a plurality of driving pulses configured to discharge the plurality of droplets from the nozzle by fluctuating the capacity of the pressure chamber more than once are used as the driving waveform, at least one driving pulse to discharge the first droplet in the plurality of droplets fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the first droplet and a pressure wave vibration excited in the pressure chamber by a prior operation have a phase shift which is -0.6 AL or more and 0.6 AL or less where AL is 1/2 of an acoustic resonant period of a pressure

wave in the pressure chamber, and at least one driving pulse to discharge the subsequent second droplet fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the second droplet and a combined vibration of a pressure wave vibration excited in the pressure chamber by a prior operation and a reverberant pressure wave vibration remaining in the pressure chamber by the discharge of the first droplet have a phase shift in a direction opposite to the phase shift in the discharge of the first droplet.

13. The method for driving an inkjet head according to claim 12, wherein a first expansion pulse which expands the capacity of the pressure chamber for a fixed time and a first contraction pulse which is applied in synchronization with end of application of the first expansion pulse and contracts the capacity of the pressure chamber for a fixed time are used as the driving pulses to discharge the first droplet, a pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, or 1.2 AL or more and 1.6 AL or less, and a pulse width of the first contraction pulse is 0.5 AL.
14. The method for driving an inkjet head according to claim 13, wherein a second expansion pulse which expands the capacity of the pressure chamber for fixed time is used as the driving pulse to discharge the second droplet, and a phase shift between a combined vibration of a pressure wave vibration excited in the pressure chamber by rising of the second expansion pulse and the reverberant pressure wave vibration remaining in the pressure chamber by the discharge of the first droplet and a pressure wave vibration excited in the pressure chamber by falling of the second expansion pulse is 0 AL or more and 1.5 AL or less when the pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, or -0.5 AL or more and 0 AL or less when the pulse width of the first expansion pulse is 1.2 AL or more and 1.6 AL or less.
15. The apparatus for driving an inkjet head according to claim 14, wherein the pulse width of the first expansion pulse is 0.4 AL or more and 0.8 AL or less, and the pulse width of the second expansion pulse is larger than 1.2 AL and is 1.9 AL or less.
16. The apparatus for driving an inkjet head according to claim 14, wherein the pulse width of the first expansion pulse

is 1.2 AL or more and 1.6 AL or less, and the pulse width of the second expansion pulse is 0.8 AL or more and 1.1 AL or less.

17. The method for driving an inkjet head according to claim 14, 15, or 16, wherein a second contraction pulse which contracts the capacity of the pressure chamber for a fixed time and cancels the reverberant pressure vibration excited in the pressure chamber is used after the second expansion pulse as the driving waveform.
18. The method for driving an inkjet head according to claim 17, wherein the second contraction pulse is applied in synchronization with end of application of the second expansion pulse, and has a pulse width of 2 AL.
19. The method for driving an inkjet head according to claim 17, wherein the second contraction pulse has a pulse width of 1 AL, and is applied after a pause time of 1 AL from end of application of the second expansion pulse.
20. The method for driving an inkjet head according to claim 17, wherein the second contraction pulse has a pulse width of 0.5 AL, and is applied in synchronization with end of application of the second expansion pulse, and a third contraction pulse which contracts the capacity of the pressure chamber for a fixed time and has a pulse width of 1 AL is applied after a pause time of 0.5 AL after end of application of the second contraction pulse as the driving waveform.
21. The method for driving an inkjet head according to any one of claims 12 to 20, wherein the driving waveform is a rectangular wave.
22. The method for driving an inkjet head according to any one of claims 12 to 21, wherein a shear-mode type inkjet head in which the pressure generator is driven in a shear mode is used as the inkjet head.
23. A method for designing a driving waveform which has a plurality of driving pulses, comprising: driving a pressure generator by application to the pressure generator in an inkjet head; fluctuating a capacity of a pressure chamber more than once to discharge a plurality of droplets from a nozzle; and combining the droplets with each other during flight or impacting the droplets within the same pixel on a recording medium, wherein at least one driving pulse to discharge the first droplet in the plurality of droplets fluctuates the

capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the first droplet and a pressure wave vibration excited in the pressure chamber by a prior operation have a phase shift which is $-0.6 AL$ or more and $0.6 AL$ or less where AL is $1/2$ of an acoustic resonant period of a pressure wave in the pressure chamber, and at least one driving pulse to discharge the subsequent second droplet fluctuates the capacity of the pressure chamber to excite two or more overlapping pressure waves in the pressure chamber, and a pressure wave vibration excited in the pressure chamber at the time of discharging the second droplet and a combined vibration of a pressure wave vibration excited in the pressure chamber by a prior operation and a reverberant pressure wave vibration remaining in the pressure chamber by the discharge of the first droplet have a phase shift in a direction opposite to the phase shift in the discharge of the first droplet.

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FIG. 1

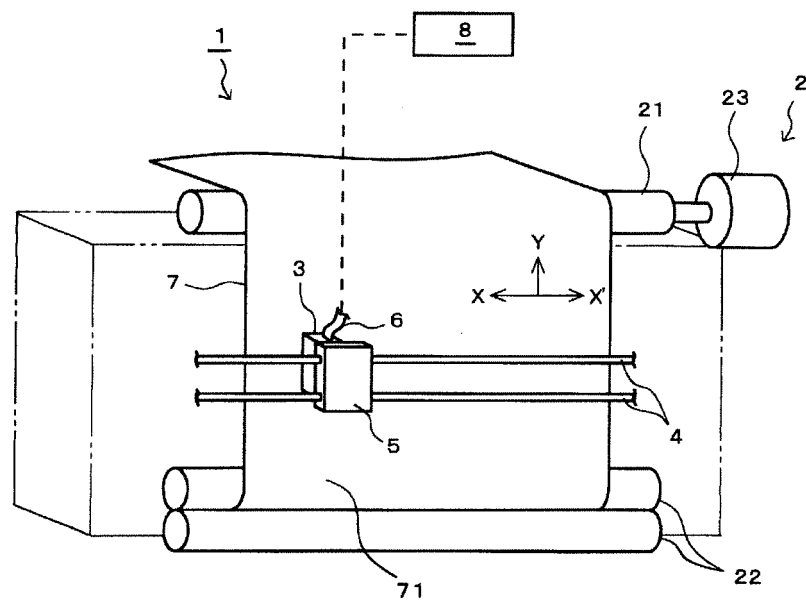


FIG. 2

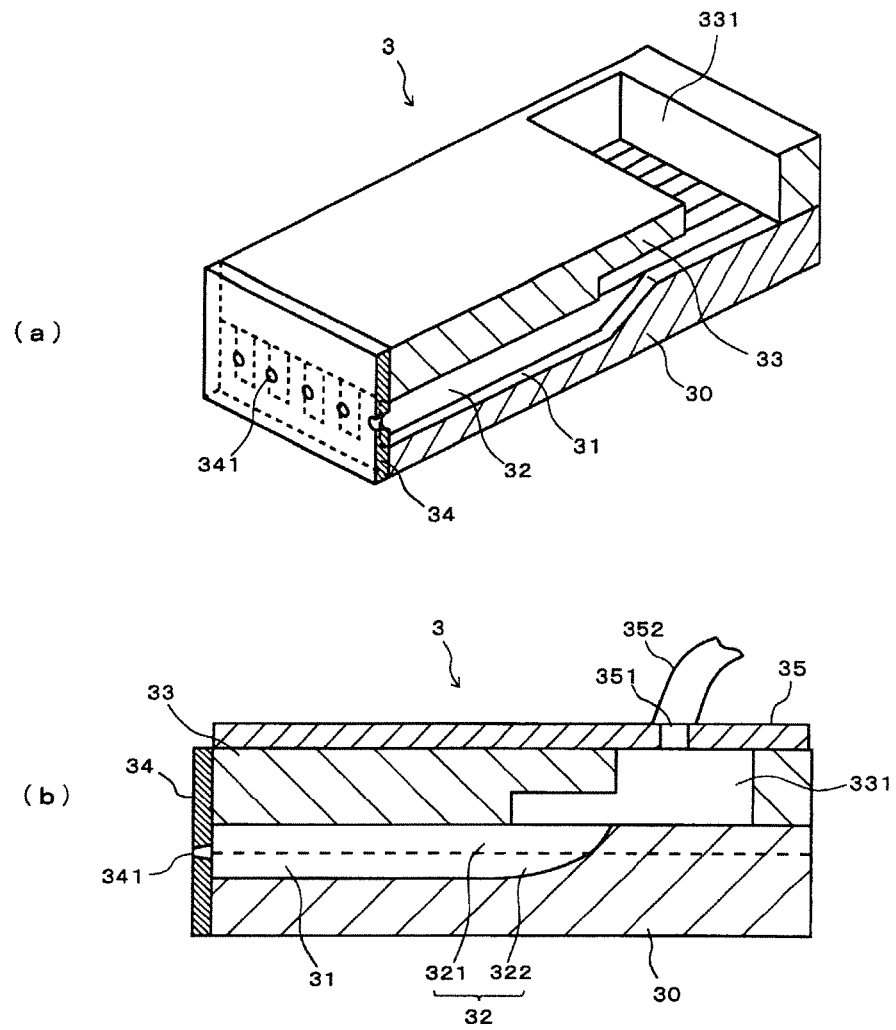


FIG. 3

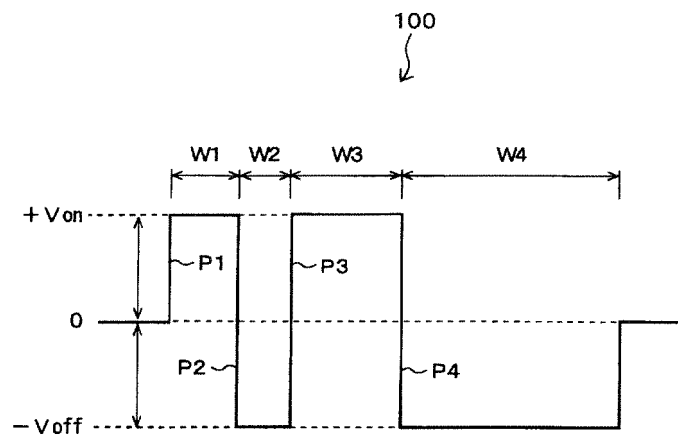


FIG. 4

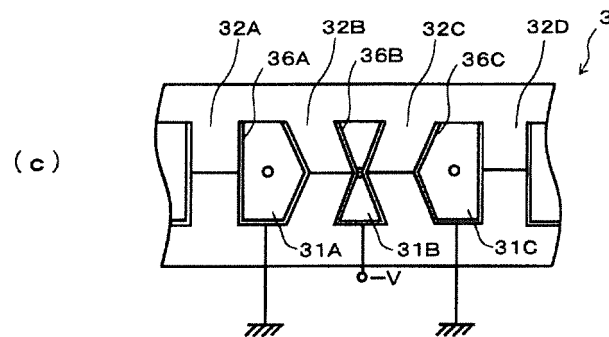
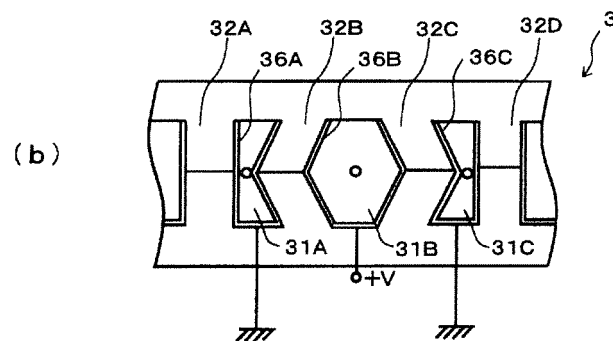
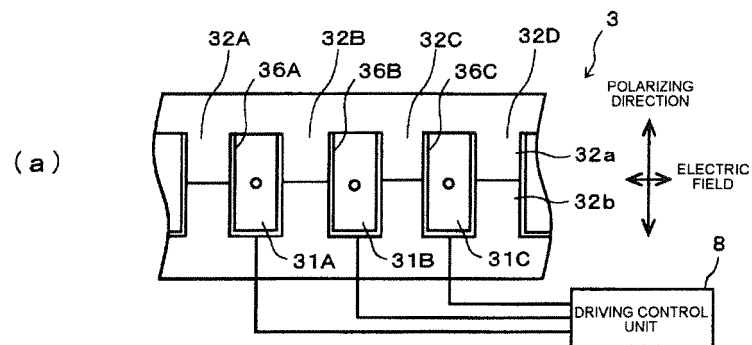


FIG. 5

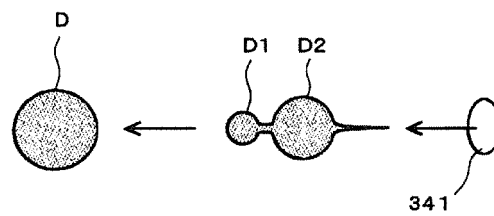


FIG. 6

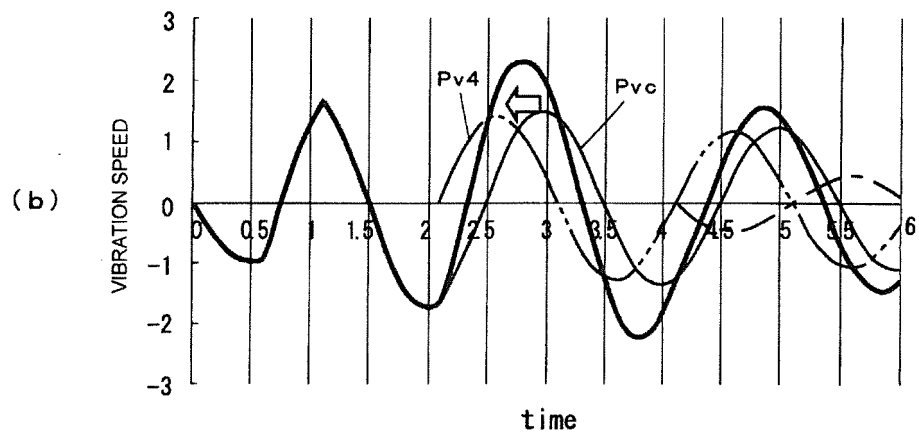
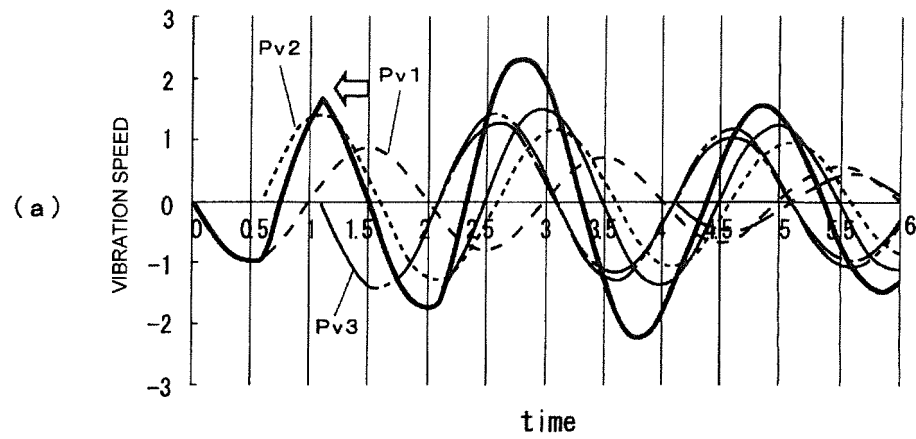


FIG. 7

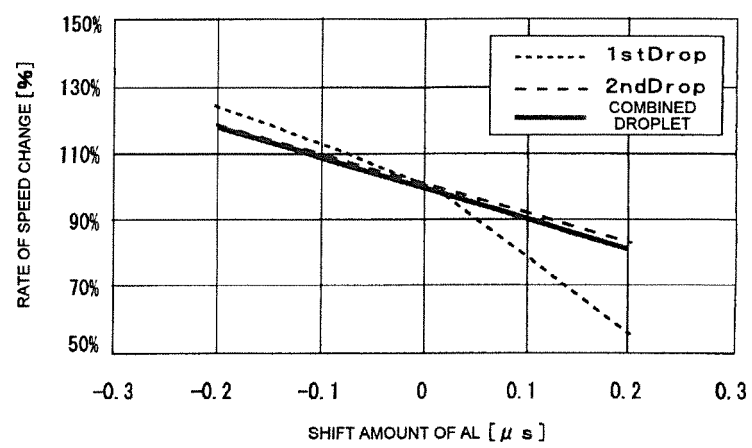


FIG. 8

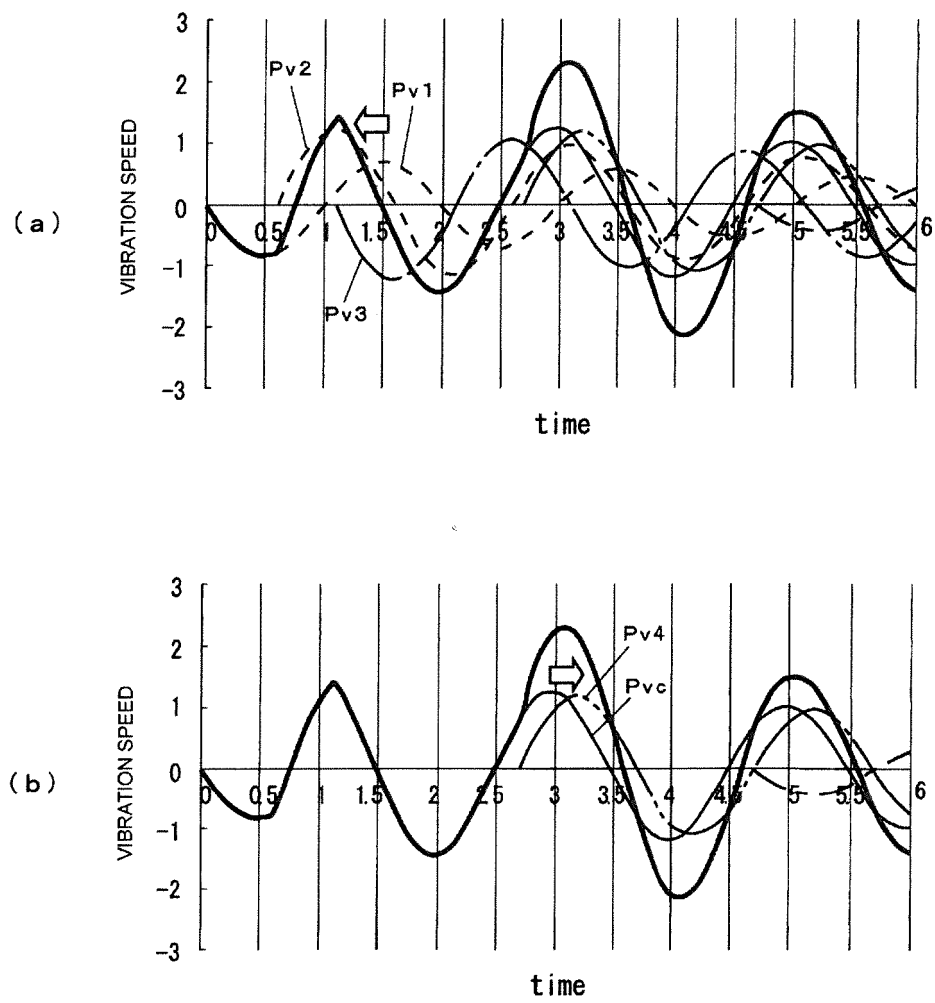


FIG. 9

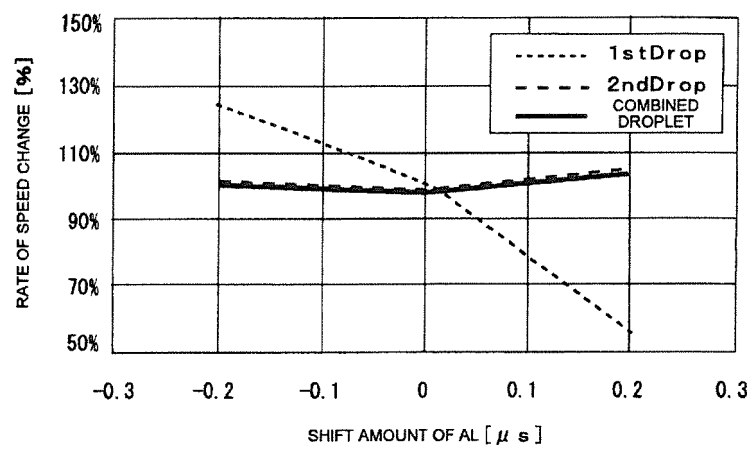


FIG. 10

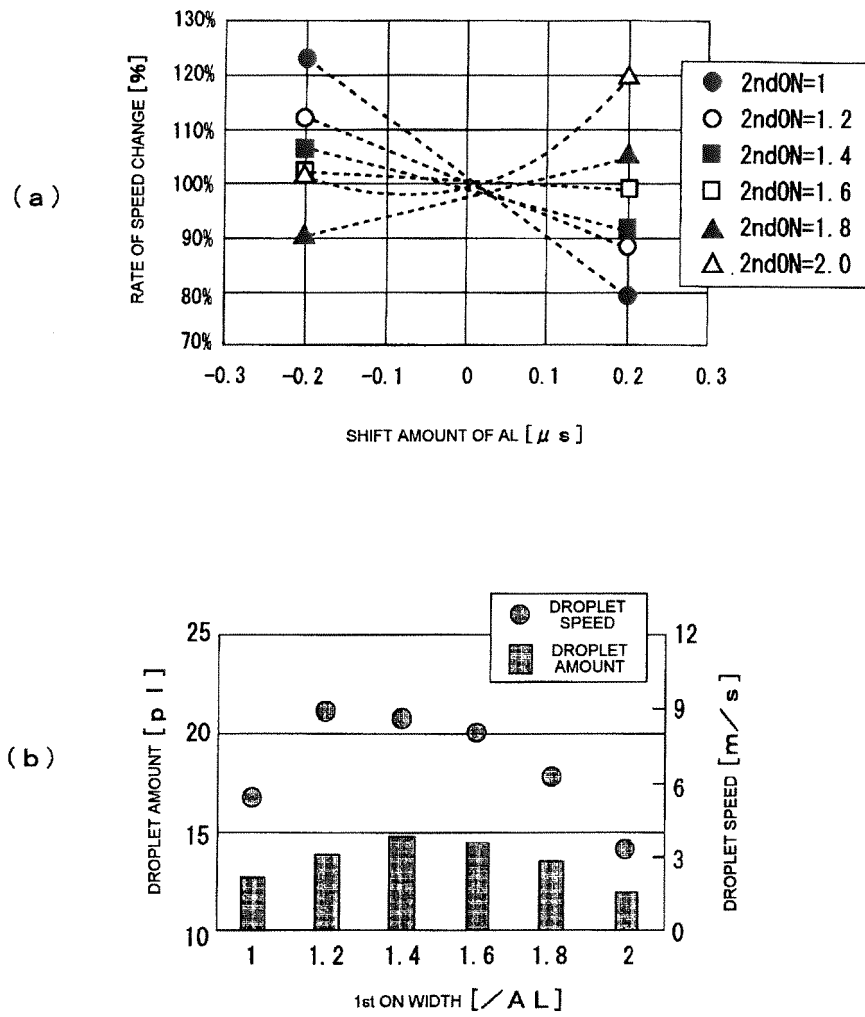


FIG. 11

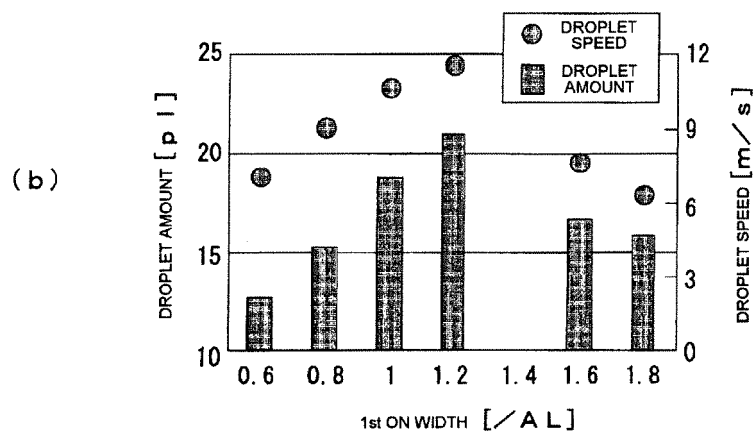
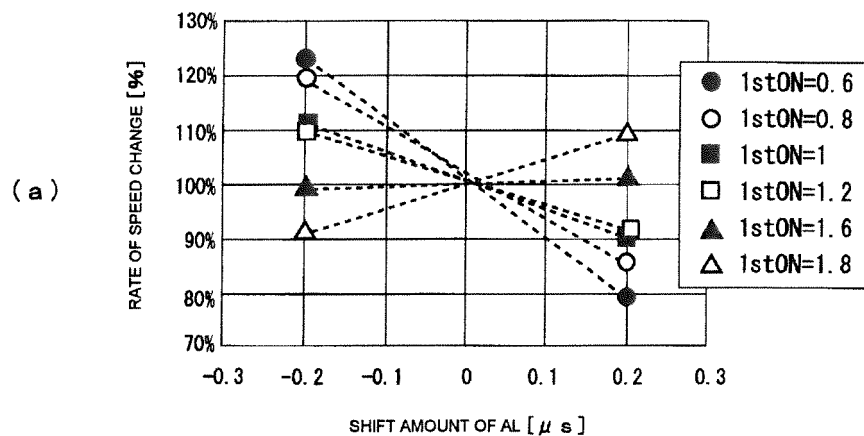


FIG. 12

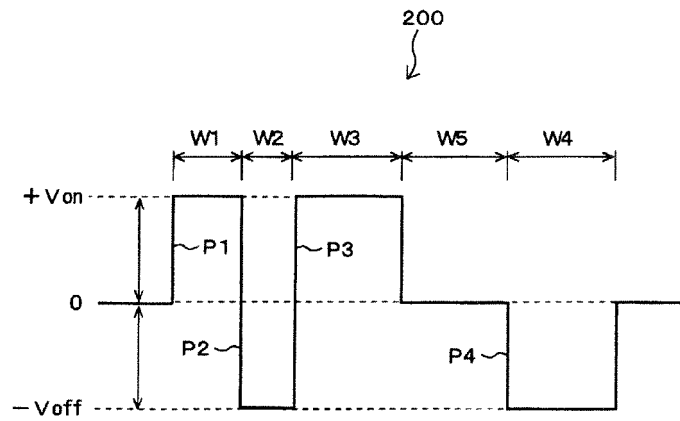


FIG. 13

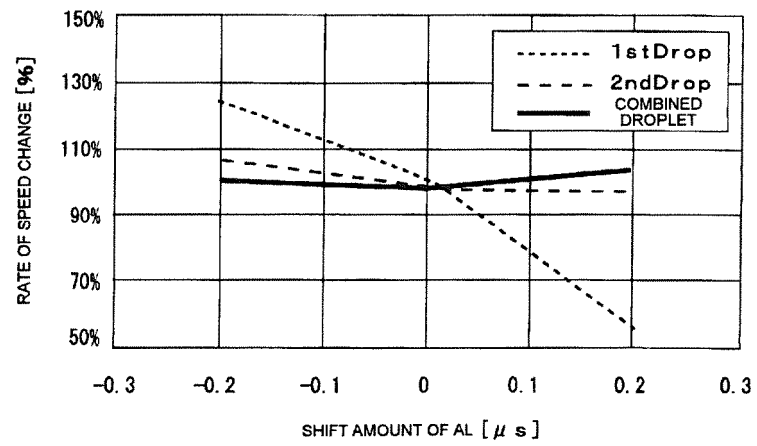


FIG. 14

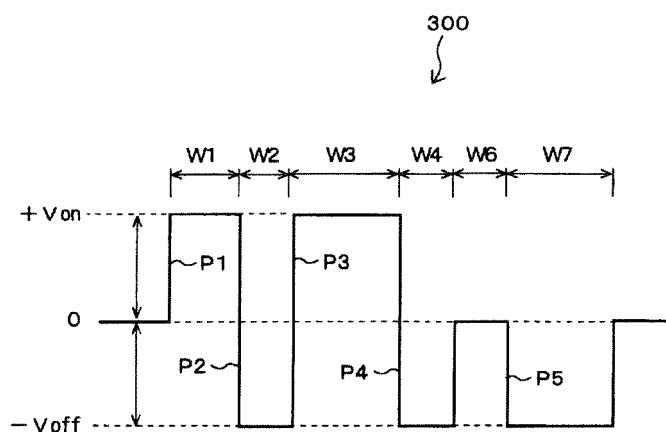


FIG. 15

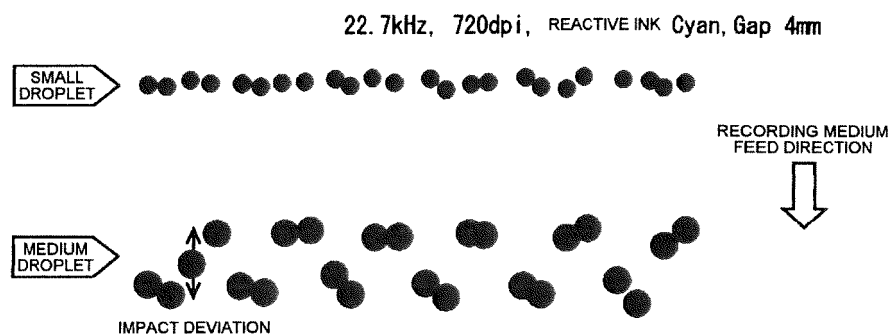


FIG. 16

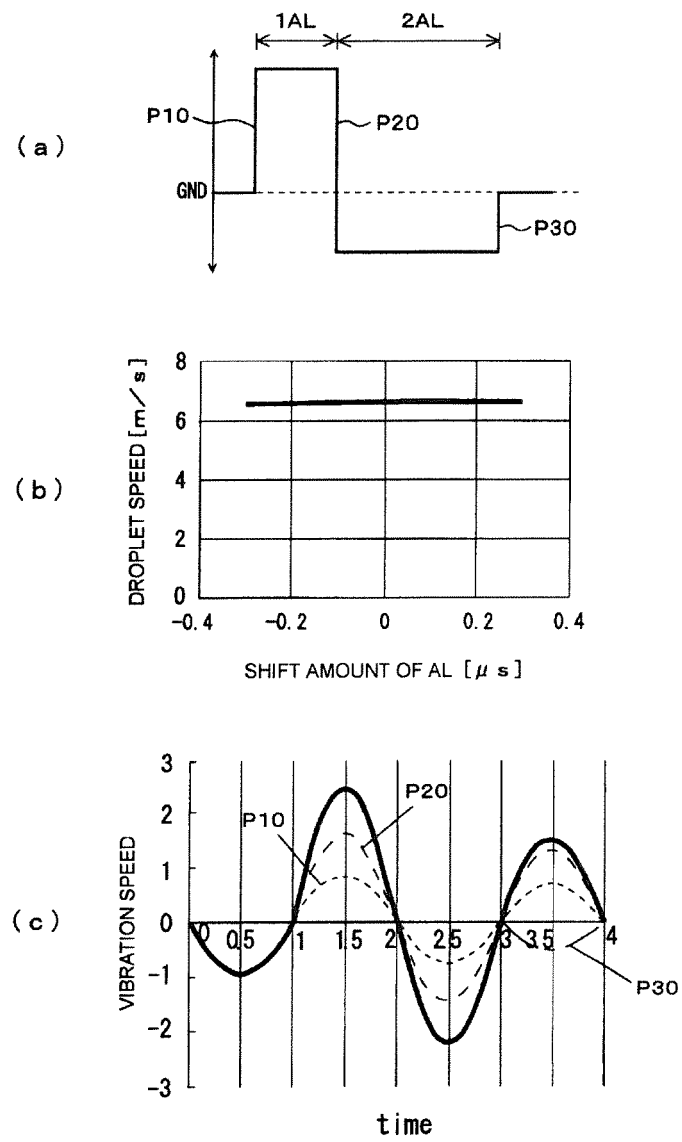


FIG. 17

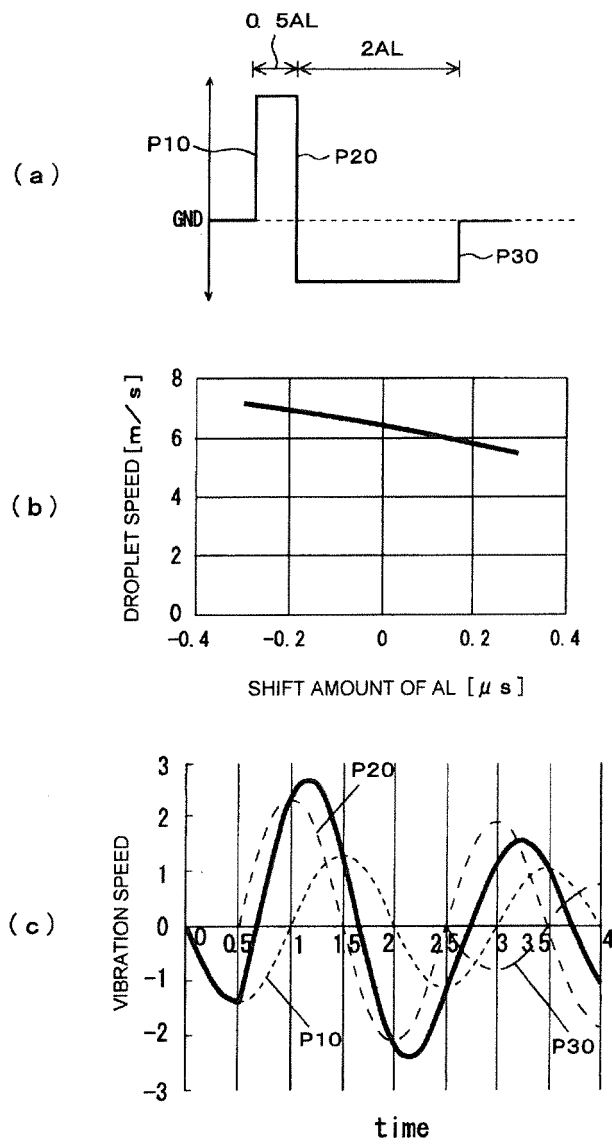
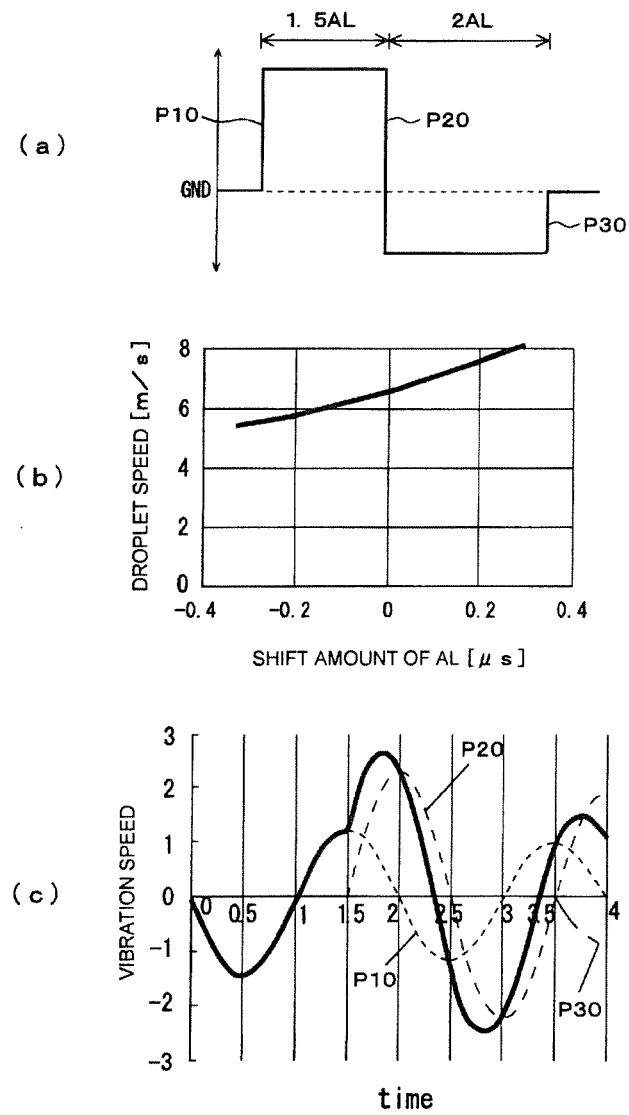


FIG. 18



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/085926

A. CLASSIFICATION OF SUBJECT MATTER

B41J2/015(2006.01)i, B41J2/045(2006.01)i, B41J2/14(2006.01)i, B41J2/205(2006.01)i

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)

B41J2/015, B41J2/045, B41J2/14, B41J2/205

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2017

Kokai Jitsuyo Shinan Koho 1971-2017 Toroku Jitsuyo Shinan Koho 1994-2017

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	WO 2015/152185 A1 (Konica Minolta, Inc.), 08 October 2015 (08.10.2015), paragraphs [0034] to [0156]; fig. 3 to 18 (Family: none)	1-23
A	JP 2001-301207 A (Konica Corp.), 30 October 2001 (30.10.2001), paragraphs [0038] to [0045]; fig. 9 to 15 (Family: none)	1-23
A	JP 2014-151502 A (Ricoh Co., Ltd.), 25 August 2014 (25.08.2014), paragraphs [0066] to [0095]; fig. 7 to 12 & US 2014/0218428 A1 paragraphs [0088] to [0117]; fig. 7 to 12	1-23

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

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Date of the actual completion of the international search
06 January 2017 (06.01.17)

Date of mailing of the international search report
17 January 2017 (17.01.17)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

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Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/085926

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2014-208411 A (Toshiba Corp.), 06 November 2014 (06.11.2014), paragraphs [0019] to [0050]; fig. 5 to 17 (Family: none)	1-23

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2000015803 A [0006]
- WO 2015152185 A [0006]
- JP 2001328259 A [0006]