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(54) **LIQUID DISCHARGE CONTROL DEVICE AND LIQUID DISCHARGE APPARATUS**

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(57) **ABSTRACT**

A control device includes circuitry to generate a drive waveform applied to an electromechanical transducer element that changes pressure in a liquid chamber communicating with a nozzle to discharge liquid. The drive waveform includes, in a pulse unit of one discharge cycle, a first discharge pulse waveform including a damping element to damp a vibration of the liquid, and a second discharge pulse waveform subsequent to the first discharge pulse waveform. The circuitry selects at least one of the first and second discharge pulse waveforms in the pulse unit, in accordance with a volume of the liquid to be discharged, to cause the nozzle to discharge different volumes of the liquid. A pulse interval between the first and second discharge pulse waveforms is from $P_{hlm}\times(N\pm 1/8)$ to $P_{hlm}\times(N\pm 1/4)$, where P_{hlm} represents a Helmholtz period of the liquid chamber and N represents an integer of 1 or greater.

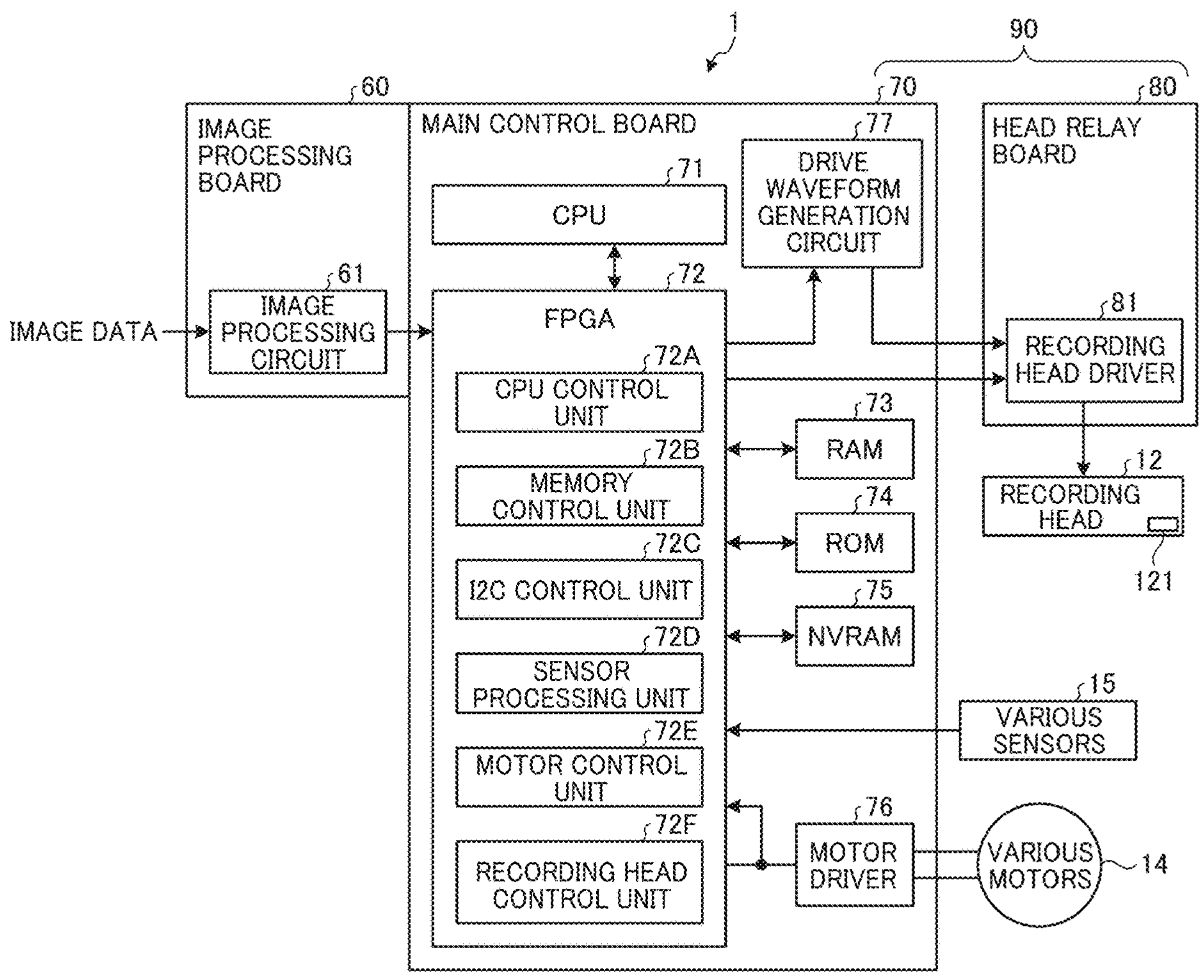
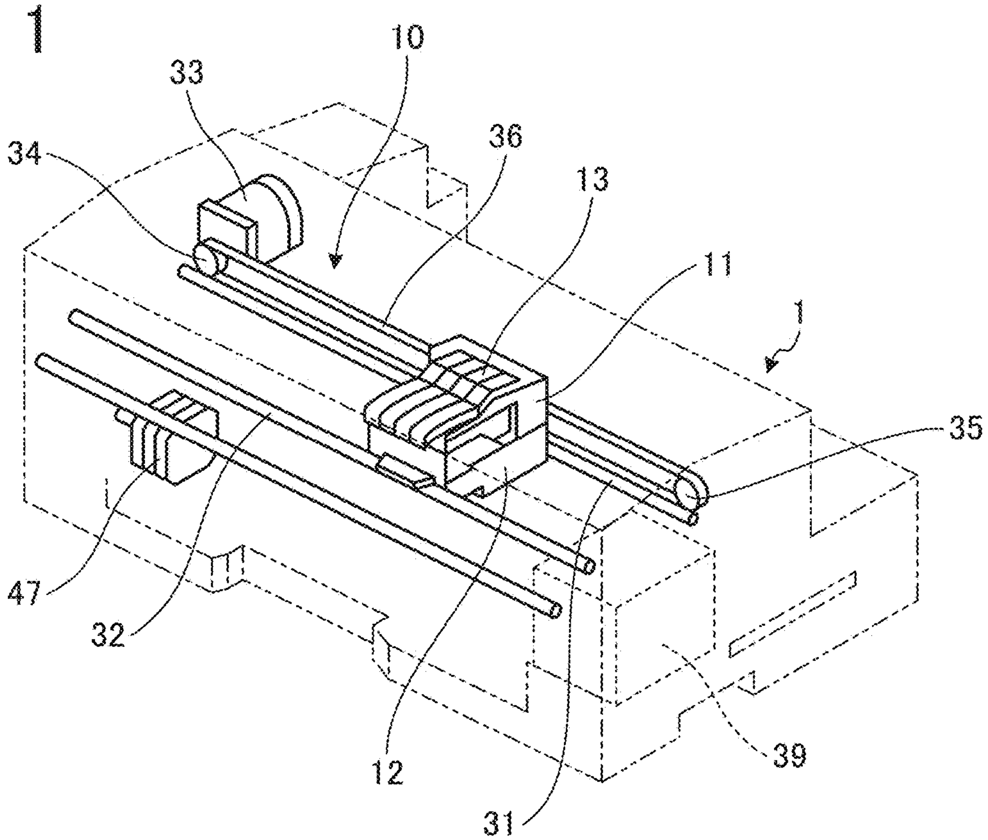
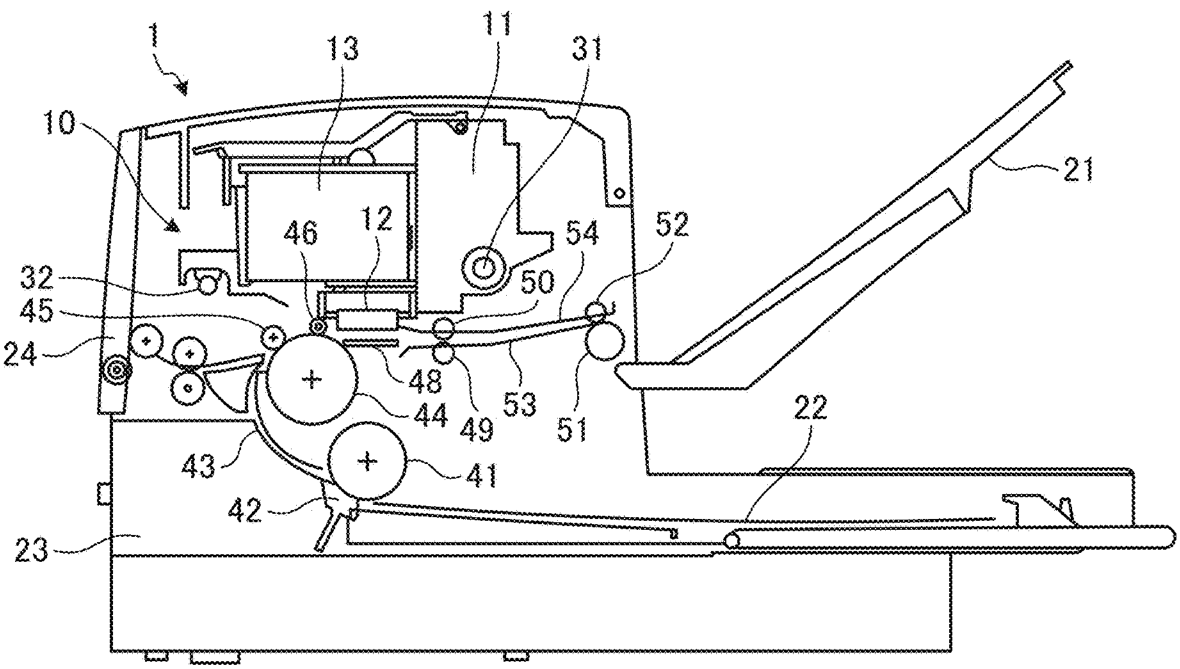


FIG. 1



10
33
36
34
13
11
1
35
47
32
12
39
31

FIG. 2



1
13
11
31
10
21
46
12
54
52
32
50
45
24
48
44
49
53
51
22
43
41
42
23

FIG. 3

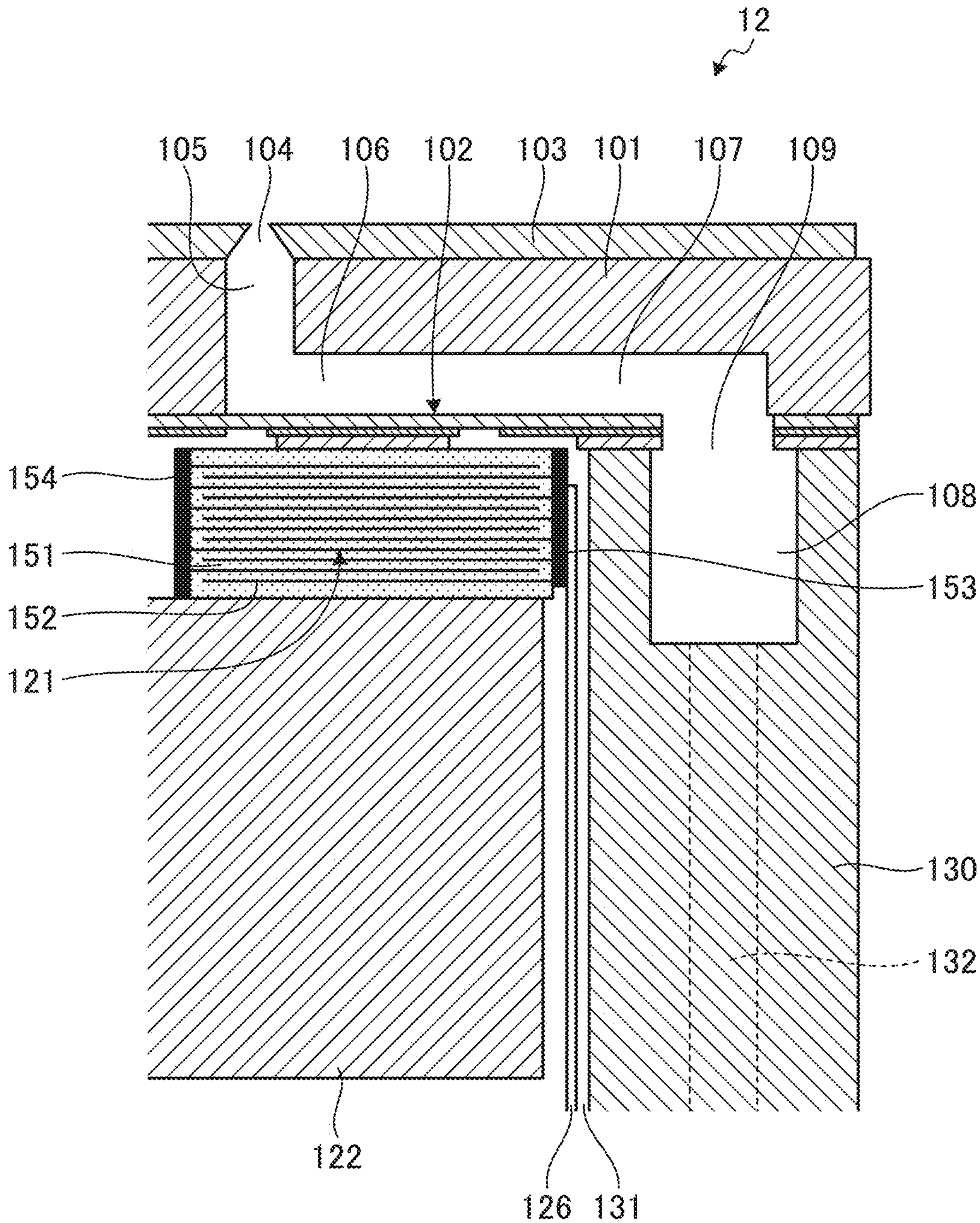

12
105
104
106
102
103
101
107
109
154
108
151
153
152
121
130
132
122
126
131

FIG. 4

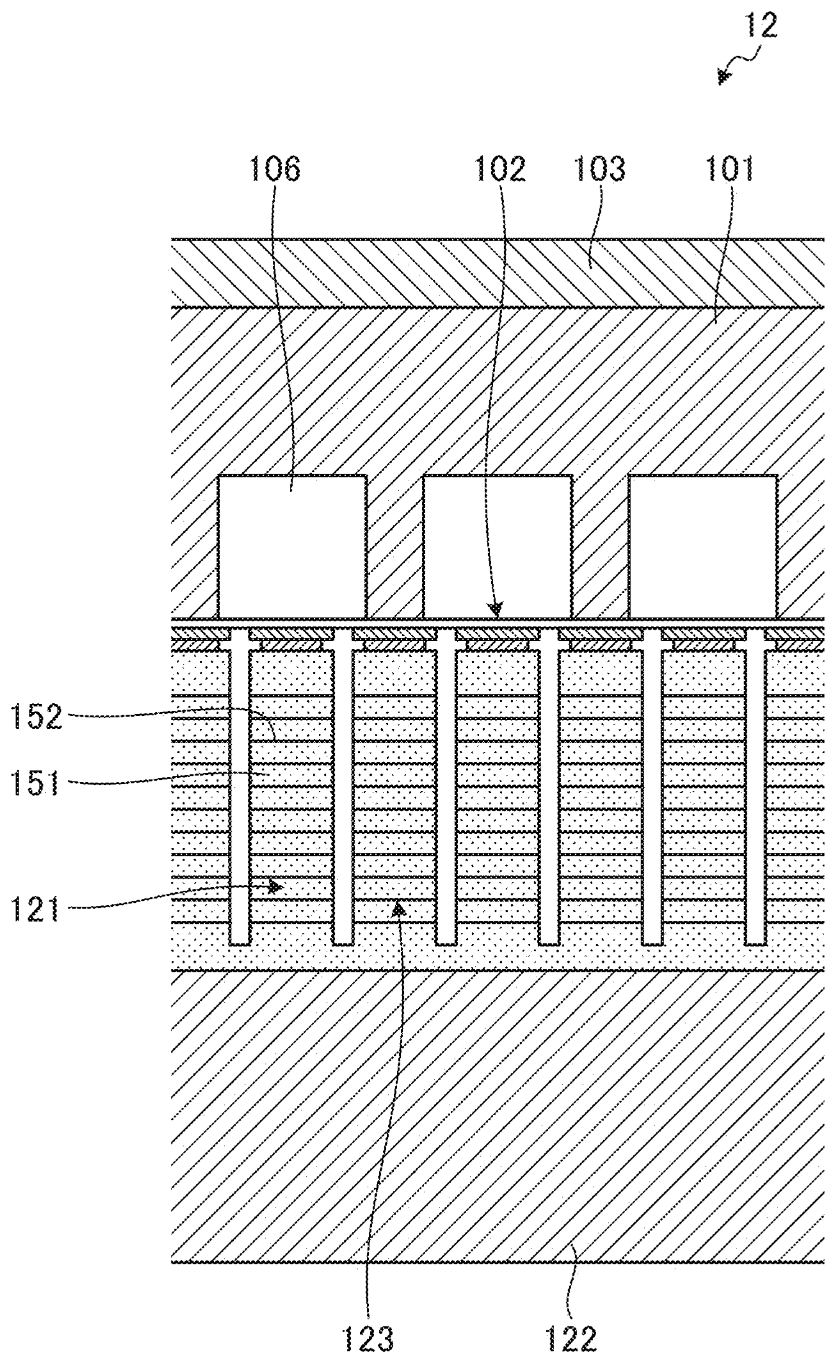


FIG. 5

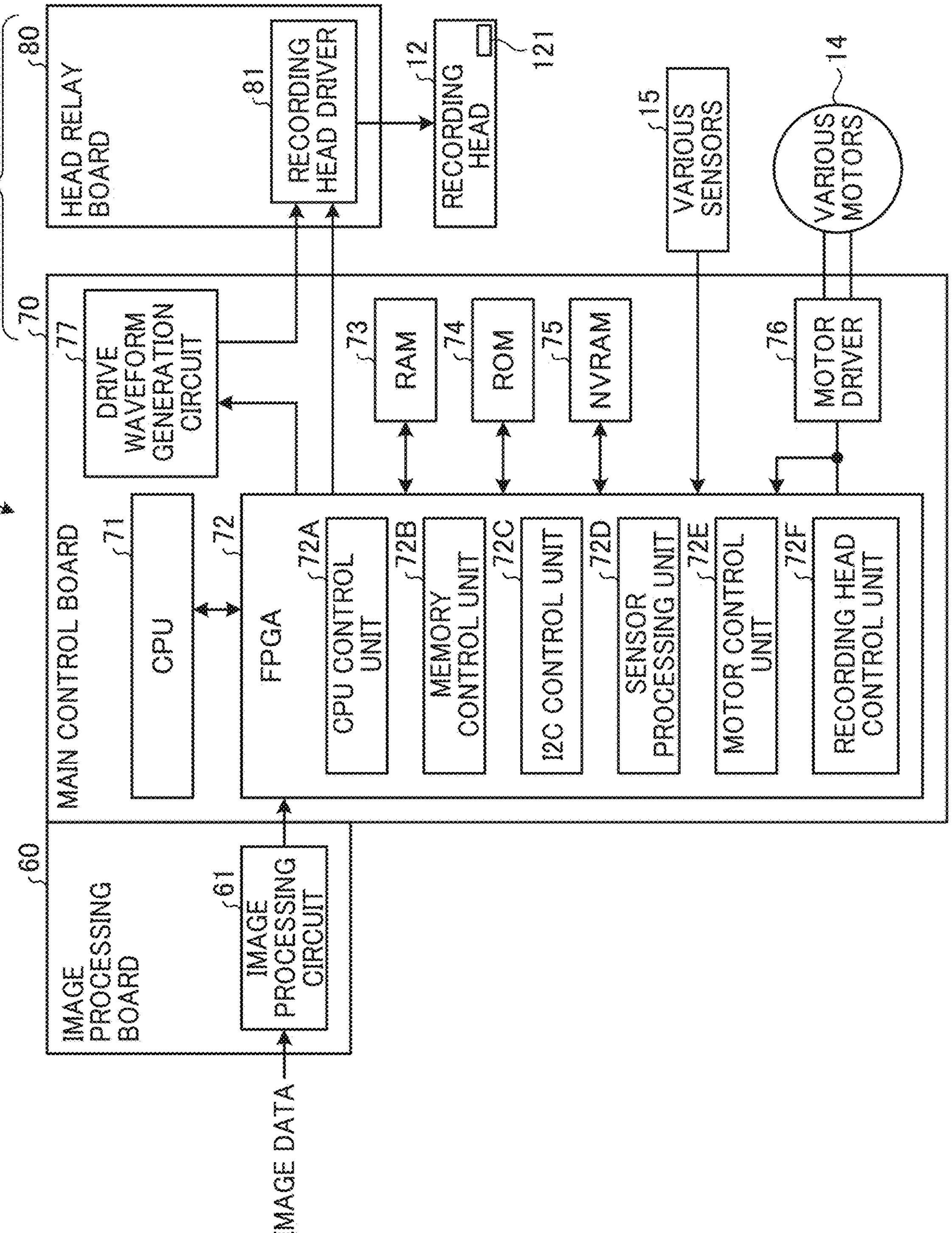

1
90
HEAD RELAY BOARD
80
RECORDING HEAD DRIVER
81
RECORDING HEAD
12
121
VARIOUS SENSORS
15
VARIOUS MOTORS
14
MAIN CONTROL BOARD
70
DRIVE WAVEFORM GENERATION CIRCUIT
77
RAM
73
ROM
74
NVRAM
75
MOTOR DRIVER
76
CPU
71
FPGA
72
CPU CONTROL UNIT
72A
MEMORY CONTROL UNIT
72B
I2C CONTROL UNIT
72C
SENSOR PROCESSING UNIT
72D
MOTOR CONTROL UNIT
72E
RECORDING HEAD CONTROL UNIT
72F
IMAGE PROCESSING BOARD
60
IMAGE PROCESSING CIRCUIT
61
IMAGE DATA

FIG. 6

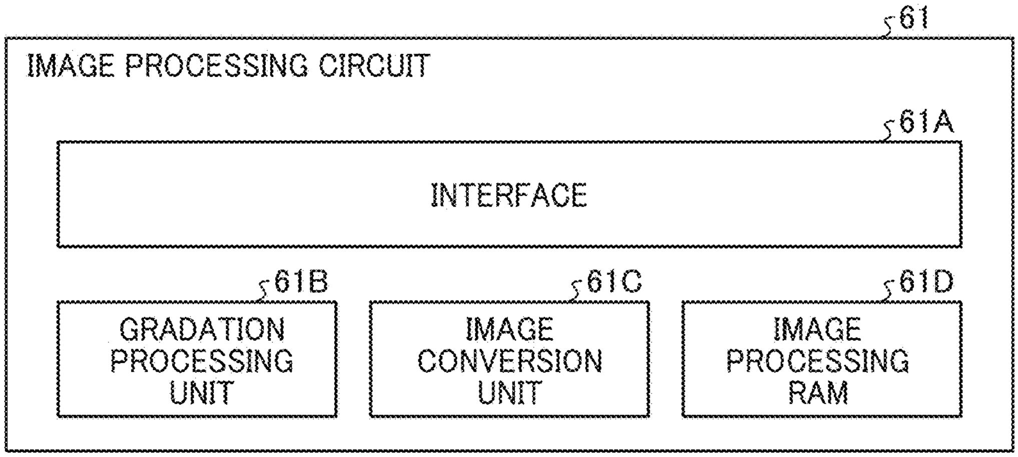

61
IMAGE PROCESSING CIRCUIT
61A
INTERFACE
61B
GRADATION PROCESSING UNIT
61C
IMAGE CONVERSION UNIT
61D
IMAGE PROCESSING RAM

FIG. 7

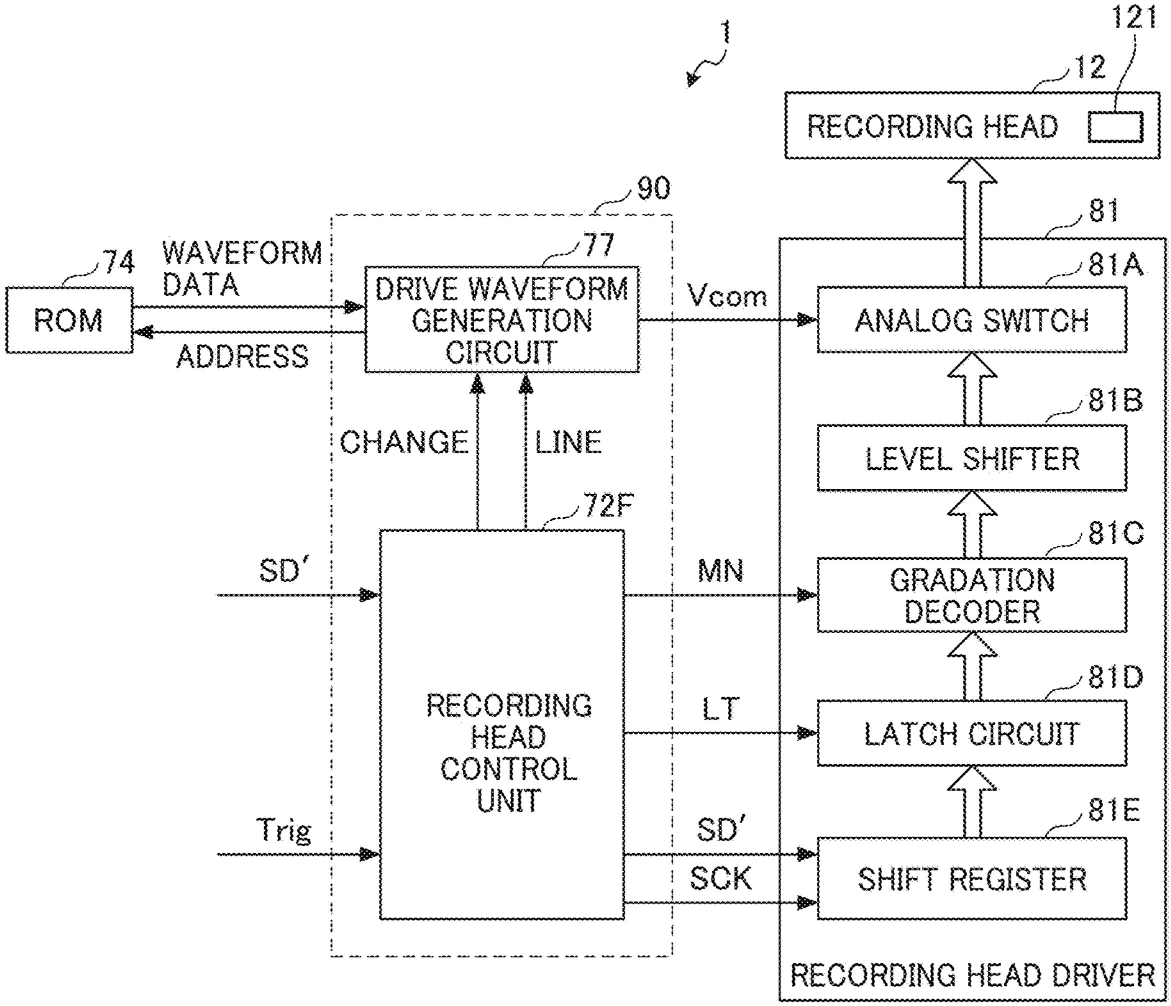

1
121
12
RECORDING HEAD
90
81
74
WAVEFORM DATA
77
DRIVE WAVEFORM GENERATION CIRCUIT
Vcom
81A
ANALOG SWITCH
ROM
ADDRESS
CHANGE
LINE
81B
LEVEL SHIFTER
72F
81C
SD′
MN
GRADATION DECODER
RECORDING HEAD CONTROL UNIT
LT
81D
LATCH CIRCUIT
Trig
SD′
81E
SCK
SHIFT REGISTER
RECORDING HEAD DRIVER

FIG. 8

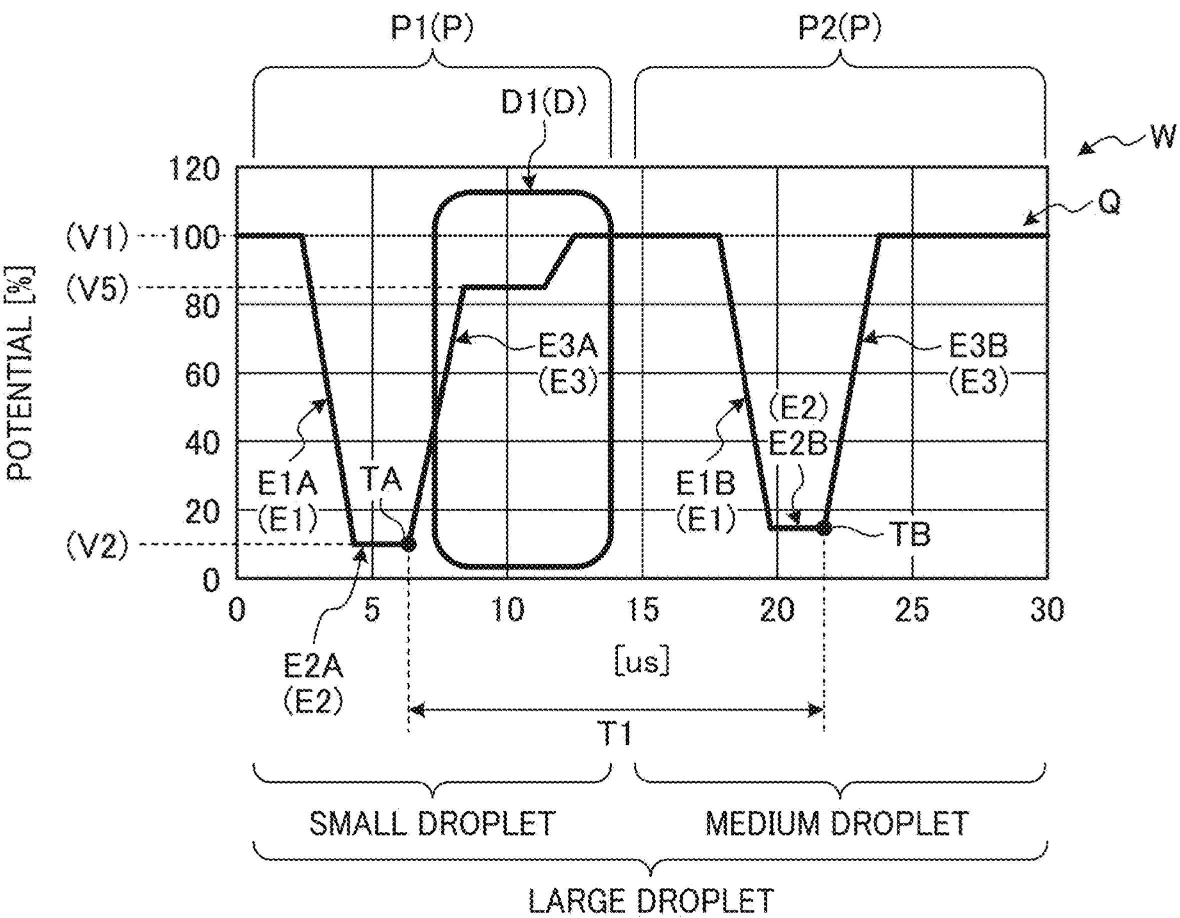

P1(P)
P2(P)
D1(D)
W
Q
120
(V1) 100
(V5)
80
60
40
20
(V2)
0
POTENTIAL [%]
E3A
(E3)
E3B
(E3)
(E2)
E2B
E1A
(E1)
TA
E1B
(E1)
TB
0
5
10
15
20
25
30
[us]
E2A
(E2)
T1
SMALL DROPLET
MEDIUM DROPLET
LARGE DROPLET

FIG. 9

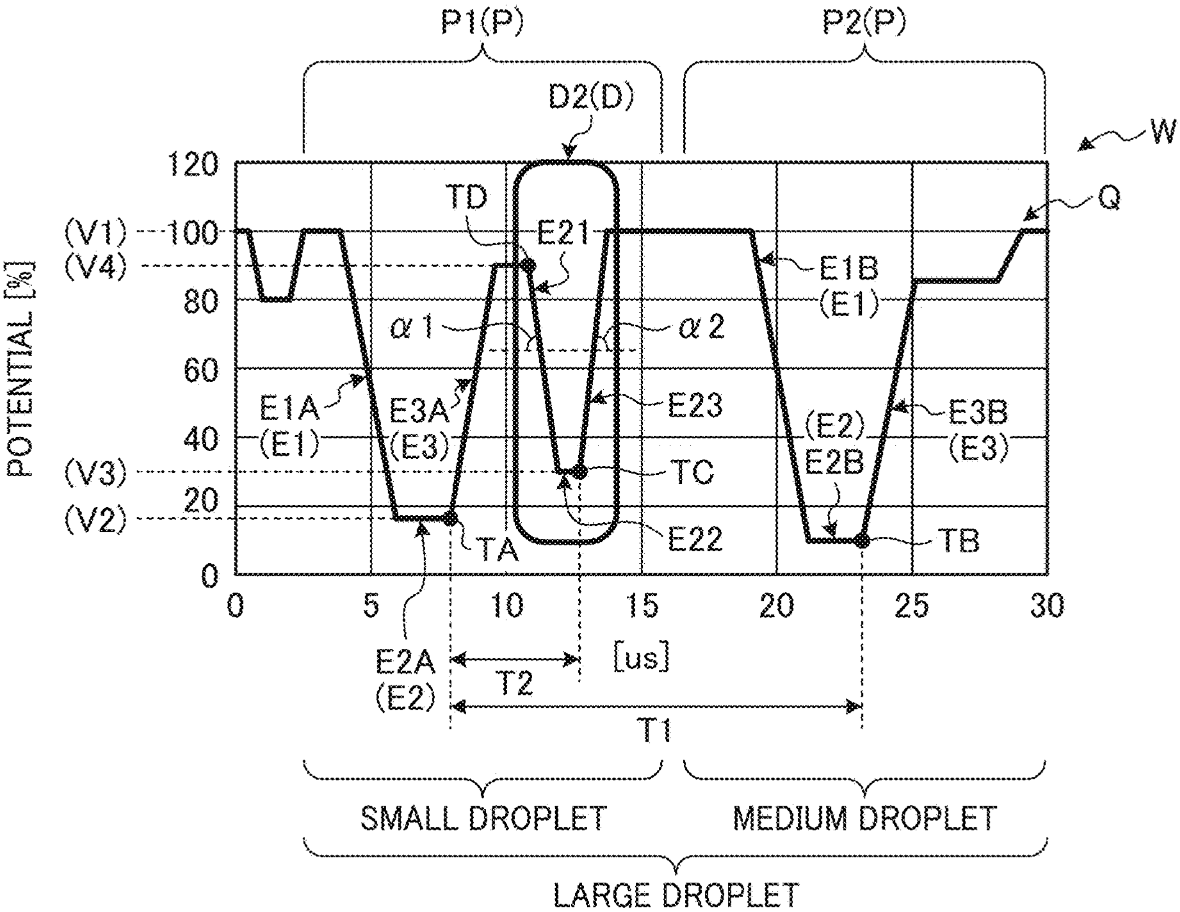

P1(P)
P2(P)
D2(D)
W
Q
120
(V1) 100
(V4)
80
60
40
(V3)
20
(V2)
0
POTENTIAL [%]
TD
E21
α1
α2
E1B
(E1)
E1A
(E1)
E3A
(E3)
E23
(E2)
E2B
E3B
(E3)
TC
E22
TA
TB
0
5
10
15
20
25
30
[us]
E2A
(E2)
T2
T1
SMALL DROPLET
MEDIUM DROPLET
LARGE DROPLET

FIG. 10

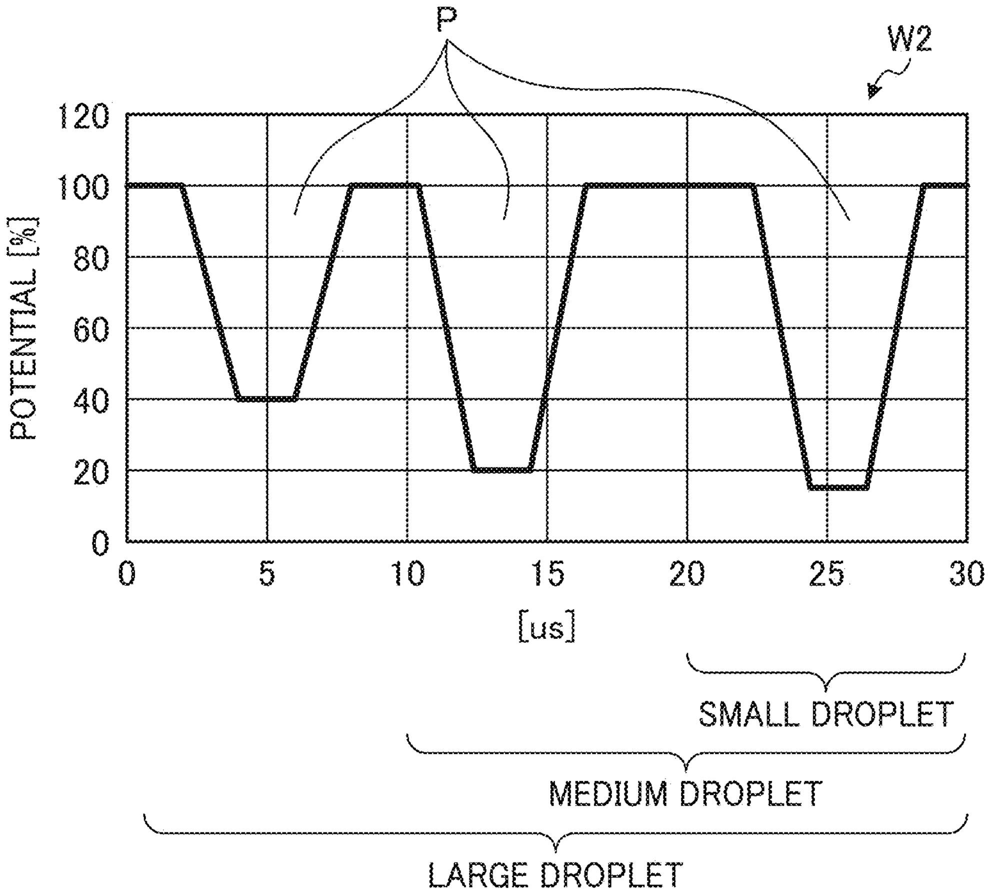
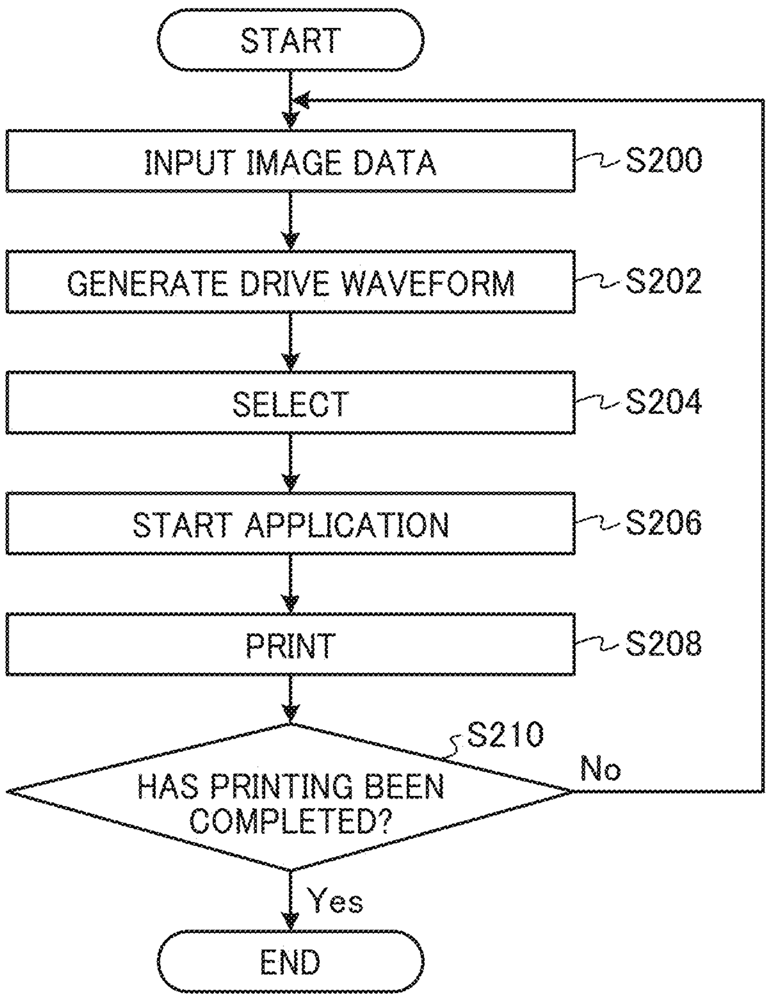

P
W2
120
100
80
60
40
20
0
POTENTIAL [%]
0
5
10
15
20
25
30
[us]
SMALL DROPLET
MEDIUM DROPLET
LARGE DROPLET

FIG. 11


START
INPUT IMAGE DATA
S200
GENERATE DRIVE WAVEFORM
S202
SELECT
S204
START APPLICATION
S206
PRINT
S208
S210
HAS PRINTING BEEN COMPLETED?
No
Yes
END

LIQUID DISCHARGE CONTROL DEVICE AND LIQUID DISCHARGE APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application is based on and claims priority pursuant to 35 U.S.C. § 119(a) to Japanese Patent Application No. 2018-215849, filed on Nov. 16, 2018 in the Japan Patent Office, the entire disclosure of which is hereby incorporated by reference herein.

BACKGROUND

Technical Field

[0002] The present disclosure relates to a liquid discharge control device and a liquid discharge apparatus.

Discussion of the Background Art

[0003] A conventional liquid discharge apparatus discharges liquid droplets, to generate an image or a shaped object. Such a liquid discharge apparatus uses a technique to selectively discharge a plurality of types of liquid droplets by adjusting the volume of liquid to be discharged, such as large droplets, medium droplets, small droplet, or no discharge.

[0004] In a known technique, one discharge pulse is selected to discharge small droplets, two discharge pulses are selected to discharge medium droplets, and three discharge pulses are selected to discharge large droplets. A drive waveform formed with these discharge pulses is supplied so that a plurality of types of liquid droplets with different volumes can be selectively discharged. Further, there is a technique of selecting whether to supply a micro-vibration pulse prior to supply of discharge pulses, thereby changing the volumes of the liquid droplets to be discharged by the discharge pulses.

SUMMARY

[0005] An embodiment of this disclosure provides a control device for discharging of a liquid. The control device includes circuitry configured to generate a drive waveform to be applied to an electromechanical transducer element configured to change a pressure in a liquid chamber communicating with a nozzle configured to discharge a liquid. The drive waveform includes a plurality of pulses in a pulse unit of one discharge cycle. The drive waveform includes a first discharge pulse waveform and a second discharge pulse waveform subsequent to the first discharge pulse waveform. The first discharge pulse waveform includes a damping element to damp a vibration of the liquid. Further, the circuitry is configured to select at least one of the first discharge pulse waveform and the second discharge pulse waveform in the pulse unit, in accordance with a volume of the liquid to be discharged, to cause the nozzle to discharge different volumes of the liquid. A pulse interval between the first discharge pulse waveform and the second discharge pulse waveform is in a range of $P_{hlm}\times(N\pm 1/8)$ to $P_{hlm}\times(N\pm 1/4)$, where P_{hlm} represents a Helmholtz period of the liquid chamber and N represents an integer of 1 or greater.

[0006] Another embodiment provides a liquid discharge apparatus that includes a nozzle configured to discharge a liquid, a liquid chamber communicating with the nozzle, an electromechanical transducer element configured to change a pressure in the liquid chamber, and the circuitry described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] A more complete appreciation of the disclosure and many of the attendant advantages and features thereof can be readily obtained and understood from the following detailed description with reference to the accompanying drawings, wherein:

[0008] FIG. **1** is a diagram illustrating an example of the overall structure of a liquid discharge apparatus according to an embodiment;

[0009] FIG. **2** is a diagram illustrating an example of a cross-section of the structure of the liquid discharge apparatus illustrated in FIG. **1**;

[0010] FIG. **3** is an example of a cross-sectional view of a recording head according to an embodiment, taken in a longitudinal direction of liquid chambers;

[0011] FIG. **4** is an example of a cross-sectional view of the recording head illustrated in FIG. **3**, taken in a short direction of liquid chambers;

[0012] FIG. **5** is a diagram illustrating an example hardware configuration of the liquid discharge apparatus illustrated in FIG. **1**;

[0013] FIG. **6** is a block diagram illustrating an example functional configuration of an image processing circuit illustrated in FIG. **5**;

[0014] FIG. **7** is a diagram for explaining the hardware configuration of the relevant components of the liquid discharge apparatus illustrated in FIG. **1**;

[0015] FIG. **8** is a chart illustrating the waveform of a pulse unit of a drive waveform according to an embodiment;

[0016] FIG. **9** is a chart illustrating an example of a drive waveform including another damping element according to an embodiment;

[0017] FIG. **10** is a chart for explaining a comparative drive waveform; and

[0018] FIG. **11** is a flowchart illustrating an example of a printing procedure according to the embodiment.

[0019] The accompanying drawings are intended to depict embodiments of the present invention and should not be interpreted to limit the scope thereof. The accompanying drawings are not to be considered as drawn to scale unless explicitly noted.

DETAILED DESCRIPTION

[0020] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present invention. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0021] In describing embodiments illustrated in the drawings, specific terminology is employed for the sake of clarity. However, the disclosure of this specification is not intended to be limited to the specific terminology so selected and it is to be understood that each specific element includes all technical equivalents that have a similar function, operate in a similar manner, and achieve a similar result.

[0022] The following is a detailed description of embodiments of a control device and a liquid discharge apparatus according to the present disclosure, with reference to the drawings.

[0023] Note that the present invention is not limited by the embodiments described below, and the components in the embodiments described below include components that can be easily conceived by those skilled in the art, components that are substantially the same, and components that fall within a so-called equivalent range. Furthermore, the components can be omitted, replaced, or modified in various manners, without departing from the scope of the embodiments described below.

[0024] Overall Structure of a Liquid Discharge Apparatus

[0025] FIG. **1** is a diagram illustrating an example of the overall structure of a liquid discharge apparatus **1** according to this embodiment. FIG. **2** is a diagram illustrating an example of a cross-section of the structure of the liquid discharge apparatus **1** according to this embodiment. Referring to FIGS. **1** and **2**, the general arrangement of the liquid discharge apparatus **1** according to this embodiment is described.

[0026] As illustrated in FIGS. **1** and **2**, the liquid discharge apparatus **1** according to this embodiment has a printing mechanism **10** that includes: a carriage **11** movable in the main scanning direction; a recording head **12** that is mounted in the carriage **11** and discharges ink; and ink cartridges **13** that supply ink to the recording head **12**. The liquid discharge apparatus **1** also includes: a sheet feeding tray **23** that is capable of loading a large number of paper sheets **22** from the front side in a lower part, and can be detachably mounted in the liquid discharge apparatus **1**; a sheet feeding tray **24** that can be opened and closed to manually feed the paper sheets **22**; and a sheet ejection tray **21** for ejecting the paper sheets **22** fed from the sheet feeding tray **23** or the sheet feeding tray **24** to the rear side after a predetermined image is printed.

[0027] The carriage **11** is slidably held in the main scanning direction by a main guide rod **31** and a sub guide rod **32** that are guide members laterally extending in the main scanning direction. The recording head **12** is a liquid discharge head that is mounted in the carriage **11**, discharges ink droplets of the respective colors of yellow (Y), cyan (C), magenta (M), and black (BK), and has a plurality of ink discharge ports (nozzles) that is arranged in a direction intersecting the main scanning direction and are designed so that the discharge direction is a downward direction.

[0028] Ink and ink droplets are examples of a liquid. The liquid to be discharged from the nozzles is not necessarily ink.

[0029] The ink cartridges **13** are replaceable and are mounted in the carriage **11**, to supply the ink of each color to the recording head **12**. The ink cartridges **13** each has an air port communicating with the air formed above each corresponding ink cartridges **13**, a supply port that supplies ink to the recording head **12** disposed below each corresponding ink cartridges **13**, and a porous member filled with the ink stored in each corresponding ink cartridge **13**. This porous member maintains the ink to be supplied to the recording head **12** at a slightly negative pressure by capillary force. The recording head **12** can be formed with a plurality of heads that discharges ink droplets of the respective colors, or can be formed with a single head having a plurality of nozzles that discharges ink droplets of the respective colors.

[0030] The liquid discharge apparatus **1** also includes: a main scanning motor **33**; a driving pulley **34** that is rotationally driven by rotation of the main scanning motor **33**; a driven pulley paired with the driving pulley **34**; and a timing belt **36** that is stretched between the driving pulley **34** and the driven pulley **35**. The carriage **11** is secured to the timing belt **36**, and reciprocates in the main scanning direction with the forward and backward rotation of the main scanning motor **33**.

[0031] The liquid discharge apparatus **1** further includes a sheet feeding roller **41**, a friction pad **42**, a guide member **43**, a conveyance roller **44**, a conveyance small roller **45**, a top end small roller **46**, and a sub scanning motor **47**.

[0032] The sheet feeding roller **41** and the friction pad **42** separate and supply paper sheets **22** from the sheet feeding tray **23**, to convey the paper sheets **22** set in the sheet feeding tray **23** to the lower side of the recording head **12**. The guide member **43** guides each paper sheet **22** separated and supplied by the sheet feeding roller **41** and the friction pad **42** to the conveyance roller **44**. The conveyance roller **44** reverses the fed paper sheet **22**, and conveys the paper sheet **22** to the lower side of the recording head **12**. The conveyance small roller **45** presses the paper sheet **22** against the peripheral surface of the conveyance roller **44**. The top end small roller **46** defines the delivery angle of the paper sheet **22** conveyed from the conveyance roller **44** to the lower side of the recording head **12**. The sub scanning motor **47** rotationally drives the sheet feeding roller **41** via a gear train.

[0033] The liquid discharge apparatus **1** also includes a print receiving unit **48**, a conveyance small roller **49**, a spur **50**, a sheet ejection roller **51**, a spur **52**, a guide member **53**, and a guide member **54**.

[0034] The print receiving unit **48** is a guide member that guides the paper sheet **22** delivered from the sheet feeding roller **41** in accordance with the movement range of the carriage **11** in the main scanning direction on the lower side of the recording head **12**. The conveyance small roller **49** and the spur **50** are disposed on the downstream side of the print receiving unit **48** in the sheet conveyance direction, and are members that are rotationally driven to feed the paper sheet **22** in the sheet ejection direction. The sheet ejection roller **51** and the spur **52** are members that are rotationally driven to deliver the paper sheet **22** delivered by the conveyance small roller **49** and the spur **50**, to the sheet ejection tray **21**. The guide members **53** and **54** are members that form a sheet ejection path.

[0035] The liquid discharge apparatus **1** further includes a recovery device **39** that is disposed at a position outside the recording region at the end of the carriage **11** in the moving direction thereof, and is designed to recover discharge defects of the recording head **12**. The recovery device **39** includes a capping unit, a suction device, and a cleaning unit. The carriage **11** moves toward the recovery device **39** while standing by for printing, and the recording head **12** is capped by the capping unit, so that the wet state of the nozzle unit is maintained. Thus, discharge defects due to drying of ink are reduced. Further, the recording head **12** discharges ink not related to recording, to make the viscosity of the ink in all the nozzles constant and maintain stable discharging performance.

[0036] In a case where the recording head **12** has a discharge defect, the capping unit seals the nozzles, the suction device sucks air bubbles and the like together with ink through a tube, and the cleaning unit removes the ink and the dust or the like adhering to the portions in the vicinities of the nozzles. Thus, the discharge defect is recovered. Further, the sucked ink is discharged into a waste ink reservoir installed at a lower portion of the main body of the liquid discharge apparatus **1**, and is absorbed and held by an ink absorber inside the waste ink reservoir.

[0037] At the time of recording (printing), the liquid discharge apparatus **1** described above drives the recording head **12** in accordance with image data while moving the carriage **11**, to discharge ink onto a stopped paper sheet **22** and perform recording of one line. After conveying the paper sheet **22** in the sub-scanning direction by a predetermined amount, the liquid discharge apparatus **1** performs recording of the next line. The liquid discharge apparatus **1** also receives a recording end signal that is a signal indicating that the bottom edge of the paper sheet **22** has reached the recording region. The liquid discharge apparatus **1** then ends the recording operation, and ejects the paper sheet **22**.

[0038] Example Configuration of the Recording Head

[0039] Next, an example configuration of the recording head **12** is described.

[0040] FIG. **3** is an example of a cross-sectional view of the recording head **12** taken in a longitudinal direction of the liquid chambers. FIG. **4** is an example of a cross-sectional view of the recording head **12** taken in a transverse direction of the liquid chambers.

[0041] The recording head **12** of this embodiment includes a channel substrate **101** formed by performing anisotropic etching on a single-crystal silicon substrate; a diaphragm **102** formed with electroformed nickel joined to the lower surface of the channel substrate **101**; and a nozzle plate **103** joined to the upper surface of the channel substrate **101**. The channel substrate **101**, the diaphragm **102**, and the nozzle plate **103** are joined and stacked, to form the recording head **12**. With these components, nozzle communication channels **105**, liquid chambers **106**, ink supply ports **109**, and the like are formed. The nozzle communication channel **105** are channels with which the nozzles **104** that discharge liquid droplets (ink droplets) communicate. The liquid chambers **106** are portions for generating pressure. The ink supply ports **109** are portions communicating with a common liquid chamber **108** for supplying ink to the liquid chambers **106** through fluid restrictors (supply channels) **107**.

[0042] Piezoelectric elements **121** are provided in the recording head **12**. The piezoelectric elements **121** are an example of electromechanical transducer elements. When voltage is applied to the electromechanical transducer elements, the electromechanical transducer elements change the pressure in the liquid chambers **106** communicating with the nozzles **104**. The piezoelectric elements **121** are pressure generator units (actuator units) for deforming the diaphragm **102** to apply pressure to the ink in the liquid chambers **106**. For example, the piezoelectric elements **121** are two rows of stacked elements. In FIG. **3**, one row of piezoelectric elements **121** is illustrated as an example.

[0043] The recording head **12** also includes a base substrate **122** onto which the piezoelectric elements **121** are bonded and secured. Further, support pillar portions **123** are provided between the piezoelectric elements **121**. The support pillar portions **123** are portions formed at the same time as the piezoelectric elements **121** through divisional processing of the piezoelectric element material. However, any drive voltage is not applied to the support pillar portions **123**, and therefore, the support pillar portions **123** serve simply as support pillars. Further, a flexible printed circuit (FPC) cable **126** on which a drive circuit (a drive integrated circuit (IC)) is mounted is connected to each piezoelectric element **121**.

[0044] The peripheral portion of the diaphragm **102** is joined to a frame member **130**. A penetrating portion **131**, a recess to be the common liquid chamber **108**, and an ink supply hole **132** are formed in the frame member **130**. The penetrating portion **131** is a portion for accommodating an actuator unit formed with the piezoelectric elements **121**, the base substrate **122**, and the like. The ink supply hole **132** is a portion for supplying ink to the common liquid chamber **108** from outside. The frame member **130** is formed by injection molding of thermosetting resin such as epoxy resin or polyphenylene sulfite, for example.

[0045] As for the channel substrate **101**, a single-crystal silicon substrate having a crystal plane orientation, for example, is subjected to anisotropic etching using an alkaline etching solution such as a potassium hydroxide aqueous solution (KOH), so that the recesses and holes to be the nozzle communication channels **105** and the liquid chambers **106** are formed. The channel substrate **101** is not necessarily formed with a single-crystal silicon substrate, and some other stainless steel substrate, a photosensitive resin, or the like can be used.

[0046] The diaphragm **102** is formed with a metal plate made of nickel. The diaphragm **102** is manufactured by an electroforming method, for example. As for the material of the diaphragm **102**, it is also possible to use some other metal plate, a joined member formed with a metal plate and a resin plate, or the like. The piezoelectric elements **121** and the support pillar portions **123** are bonded to the diaphragm **102** with an adhesive, and the frame member **130** is further bonded to the diaphragm **102** with an adhesive.

[0047] In the nozzle plate **103**, nozzles **104** each having a diameter of 10 to 30 μm are formed for the respective liquid chambers **106**, and are bonded to the channel substrate **101** with an adhesive. The nozzle plate **103** has a water repellent layer formed as an outermost surface via a predetermined layer on the surface of the nozzle forming member formed with a metal member.

[0048] The piezoelectric elements **121** are stacked piezoelectric elements (PZT in this case) in which piezoelectric materials **151** and internal electrodes **152** are alternately stacked. An individual electrode **153** and a common electrode **154** are connected to the respective internal electrodes **152** drawn to alternately different end faces of the piezoelectric elements **121**. In this embodiment, changes in the piezoelectric direction of the piezoelectric elements **121** are used to apply pressure to the ink in the liquid chambers **106**. Alternatively, a row of piezoelectric elements **121** can be provided in a single base substrate **122**.

[0049] In the recording head **12** designed in this manner, the voltage to be applied to the piezoelectric elements **121** is lowered from a first potential so that the piezoelectric elements **121** contract, and the diaphragm **102** descends to increase the volume of the liquid chambers **106**. As a result, the ink flows into the liquid chambers **106**. The first potential is a predetermined reference potential. After that, the voltage to be applied to the piezoelectric elements **121** is made higher, to extend the piezoelectric elements **121** in the stacking direction. The diaphragm **102** is then deformed toward the nozzles **104**, to reduce the volume/size of the liquid chambers **106**. As a result, pressure is applied to the ink in the liquid chambers **106**, and ink droplets are discharged (ejected) from the nozzles **104**.

[0050] The voltage to be applied to the piezoelectric elements **121** is then returned to the first potential, so that the diaphragm **102** is restored to the initial position, and the liquid chambers **106** expand to generate a negative pressure. At this stage, the liquid chambers **106** are filled with ink from the common liquid chamber **108**. After the vibration of the meniscus surfaces of the nozzles **104** is attenuated and stabilized, the operation for the next droplet discharge is started.

[0051] The method of driving the recording head **12** is not limited to the above described example (pull-push discharge), but pulling discharge and pushing discharge can be performed depending on how the drive waveform is generated.

[0052] Example Hardware Configuration of the Liquid Discharge Apparatus

[0053] Next, an example hardware configuration of the liquid discharge apparatus **1** of this embodiment is described.

[0054] FIG. **5** is a diagram illustrating an example hardware configuration of the liquid discharge apparatus **1** according to this embodiment.

[0055] The liquid discharge apparatus **1** according to this embodiment includes an image processing board **60**, a main control board **70**, and a head relay board **80**. The main control board **70** and the head relay board **80** correspond to a control device **90** of the liquid discharge apparatus **1**.

[0056] The image processing board **60** is a circuit board that performs image processing on input image data. The image processing board **60** includes an image processing circuit **61** that performs image processing on image data.

[0057] Based on the image data subjected to image processing, the main control board **70** generates the drive waveform for driving the piezoelectric elements **121** that discharge ink droplets for performing printing on a paper sheet **22**, determines a bias voltage, and issues a command to apply the voltage for driving the piezoelectric elements **121** to the head relay board **80**.

[0058] The main control board **70** includes a central processing unit (CPU) **71**, a field-programmable gate array (FPGA) **72**, a random access memory (RAM) **73**, a read only memory (ROM) **74**, a non-volatile RAM (NVRAM) **75**, a motor driver **76**, and a drive waveform generation circuit **77**.

[0059] The CPU **71** is an arithmetic device that controls the overall operation of the liquid discharge apparatus **1**. The CPU **71** uses the RAM **73** as a work area, and executes various kinds of control programs stored in the ROM **74**, to output control commands for controlling various kinds of operations in the liquid discharge apparatus **1**. While communicating with the FPGA **72**, The CPU **71** controls various kinds of operations in the liquid discharge apparatus **1** in cooperation with the FPGA **72**.

[0060] The FPGA **72** is an integrated circuit that controls various kinds of operations in the liquid discharge apparatus **1** in cooperation with the CPU **71**. The FPGA **72** includes a CPU control unit **72**A, a memory control unit **72**B, an inter-integrated circuit (I2C) control unit **72**C, a sensor processing unit **72**D, a motor control unit **72**E, and a recording head control unit **72**F.

[0061] The CPU control unit **72**A has a function to communicate with the CPU **71**. The memory control unit **72**B has a function to access the RAM **73** and the ROM **74**. The I2C control unit **72**C has a function to access the NVRAM **75**.

[0062] The sensor processing unit **72**D processes sensor signals from various sensors **15**. The various sensors **15** are a generic term for sensors that detect various states in the liquid discharge apparatus **1**. The various sensors **15** include an encoder sensor, a sheet sensor that detects passage of a paper sheet (a recording sheet), a cover sensor that detects opening/closing of a cover member, a temperature and humidity sensor that detects the environmental temperature and humidity, a sheet securing lever sensor that detects an operation state of a lever for securing a paper sheet, and a remaining amount detecting sensor that detects the remaining amount of the ink in the cartridge. Further, analog sensor signals that are output from the various sensors **15** are converted into digital signals by an analog-to-digital (AD) converter mounted on the main control board **70** or the like, and are input to the FPGA **72**, for example.

[0063] The motor control unit **72**E controls various motors **14**. The various motors **14** are a general term for motors included in the liquid discharge apparatus **1**. The various motors **14** include the main scanning motor **33** for operating the carriage **11**, the sub scanning motor **47** for conveying a paper sheet **22** in the sub-scanning direction, and a sheet feeding motor for feeding paper sheets **22**.

[0064] An example of operation control to be performed on the main scanning motor **33** is now described. More specifically, a specific example of control to be performed by cooperation between the CPU **71** and the motor control unit **72**E of the FPGA **72** is now described.

[0065] First, the CPU **71** instructs the motor control unit **72**E to start operating the main scanning motor **33**, and notifies the motor control unit **72**E of the moving velocity and the moving distance of the carriage **11**. Upon receipt of this instruction, the motor control unit **72**E generates a drive profile based on the information about the moving velocity and the moving distance sent from the CPU **71**, and calculates and outputs a pulse width modulation (PWM) command value to the motor driver **76**, while performing comparison with an encoder value of an encoder sensor acquired from the sensor processing unit **72**D.

[0066] After ending the predetermined operation, the motor control unit **72**E notifies the CPU **71** of the end of the operation. Although an example in which the motor control unit **72**E generates a drive profile has been described, the CPU **71** may generate a drive profile and issues an instruction to the motor control unit **72**E. The CPU **71** also performs counting of the number of printed sheets, counting of the number of scanning operation by the main scanning motor **33**, and the like.

[0067] The recording head control unit **72**F sends the head drive data stored in the ROM **74**, a discharge synchronization signal LINE, and a discharge timing signal CHANGE to the drive waveform generation circuit **77**, and causes the drive waveform generation circuit **77** to generate a drive waveform. The drive waveform generated by the drive waveform generation circuit **77** is output to a recording head driver **81** mounted on the head relay board **80**.

[0068] FIG. **6** is a block diagram illustrating an example functional configuration of the image processing circuit **61** of the image processing board **60**.

[0069] The image processing circuit **61** performs gradation processing, an image conversion process, and the like on received image data, to convert the received image data into image data in a format that can be processed by the recording head control unit **72**F. The image processing circuit **61** then outputs the converted image data to the recording head control unit **72**F of the main control board **70**.

[0070] Specifically, the image processing circuit **61** includes an interface **61**A, a gradation processing unit **61**B, an image conversion unit **61**C, and an image processing RAM **61**D.

[0071] The interface **61**A is an input unit of image data, and is a communication interface with the CPU **71** and the FPGA **72**. The gradation processing unit **61**B performs gradation processing on the received multivalued image data, to convert the multivalued image data into small-value image data. The small-value image data is image data at the gradation level equal to the type of liquid droplets (large droplets, medium droplets, or small droplets) to be discharged by the recording head **12**. The gradation processing unit **61**B then holds at least one band of the converted image data in the image processing RAM **61**D.

[0072] One band of image data refers to image data corresponding to the maximum width in the sub-scanning direction that can be recorded by the recording head **12** in one scanning operation in the main-scanning direction X.

[0073] The image conversion unit **61**C performs image data conversion on one band of image data in the image processing RAM **61**D by the image unit to be output in one scanning operation in the main-scanning direction X. This conversion is performed depending on the configuration of the recording head **12**, in accordance with information about the sequence of printing and the print width (=the sub-scanning width of image recording per one scanning operation) received from the CPU **71** via the interface **61**A.

[0074] The sequence of printing and the print width can be one-pass printing in which an image is formed by one main scanning operation on a recording medium, or can be multi-pass printing in which an image is formed by main scanning operations on the same region on a paper sheet **22** with the same nozzles or different nozzles. Alternatively, heads can be aligned in the main-scanning direction, and printing can be performed on the same region with different nozzles. These recording methods can be used in combination as appropriate. The print width indicates the width in the sub-scanning direction Y of an image recorded by the recording head **12** performing a scanning operation once (one scan) in the main-scanning direction X. In this embodiment, the print width is set by the CPU **71**.

[0075] The image conversion unit **61**C outputs the converted image data to an image recording unit via the interface **61**A.

[0076] The functions of the image processing circuit **61** can be implemented as the functions of hardware such as an FPGA or an application-specific integrated circuit (ASIC), or can be implemented by an image processing program stored in a storage device in the image processing circuit **61**. Alternatively, the functions of the image processing circuit **61** can be implemented not in the liquid discharge apparatus **1**, but by software installed in a computer.

[0077] Referring now to FIG. **7**, the hardware configuration of the relevant components of the liquid discharge apparatus **1** is further described. FIG. **7** is a diagram illustrating an example hardware configuration of the relevant components of the liquid discharge apparatus **1**. In FIG. **7**, the drive waveform generation circuit **77** and the recording head control unit **72**F are illustrated as components included in a control device **90**.

[0078] When the recording head control unit **72**F receives a trigger signal Trig that triggers the timing of discharge, the recording head control unit **72**F outputs a discharge synchronization signal LINE that triggers generation of a drive waveform, to the drive waveform generation circuit **77**. The recording head control unit **72**F further outputs a discharge timing signal CHANGE indicating the amount of delay from the discharge synchronization signal LINE, to the drive waveform generation circuit **77**.

[0079] The drive waveform generation circuit **77** is an example of a drive waveform generation unit. The drive waveform generation circuit **77** is not necessarily formed with a circuit, but can be formed with software. In this embodiment, a case where the drive waveform generation circuit **77** is a circuit is described as an example.

[0080] Using waveform data read from the ROM **74**, the drive waveform generation circuit **77** generates a drive waveform Vcom at the timing based on the discharge synchronization signal LINE and the discharge timing signal CHANGE. In this embodiment, the drive waveform Vcom is a signal that includes a plurality of discharge pulses in a pulse unit that is one discharge cycle, and is represented by a waveform. The drive waveform to be used in this embodiment will be described later in detail.

[0081] The recording head control unit **72**F also receives image data SD' subjected to image processing from the image processing circuit **61** (see FIG. **5**), and, based on the image data SD', generates a mask control signal MN for selecting a discharge pulse for each pulse unit in the drive waveform Vcom in accordance with the size of the ink droplets to be discharged from the respective nozzles of the recording head **12**. The mask control signal MN is a signal of the timing synchronized with the discharge timing signal CHANGE. The recording head control unit **72**F then transmits the image data SD', a synchronous clock signal SCK, a latch signal LT serving as an instruction to latch the image data SD', and the generated mask control signal MN to the recording head driver **81**.

[0082] The recording head driver **81** is an example of a selection unit. The recording head driver **81** selects, for each pulse unit, a discharge pulse included in the drive waveform given from the drive waveform generation circuit **77**, based on serially-input image data corresponding to one line of the recording head **12**.

[0083] The recording head driver **81** applies a drive waveform including the pulse unit containing the selected discharge pulse to the piezoelectric elements **121**, which are an example of an electromechanical transducer element. By doing so, the recording head driver **81** drives the piezoelectric elements **121** of the recording head **12**. In this embodiment, the recording head driver **81** selects a discharge pulse included in a pulse unit in accordance with the volume of liquid to be discharged (large droplets, medium droplets, small droplets, or no discharge, for example). In this manner, the recording head driver **81** can change the volume of liquid to be discharged from the nozzles **104** by application of a pulse unit. For example, the recording head driver **81** can select one or more types of liquid droplets having different volumes, such as large droplets, medium droplets, small droplets, and no discharge.

[0084] Specifically, the recording head driver **81** includes a shift register **81**E, a latch circuit **81**D, a gradation decoder **81**C, a level shifter **81**B, and an analog switch **81**A.

[0085] The shift register **81**E receives the image data SD' and the synchronous clock signal SCK transmitted from the recording head control unit **72**F. The latch circuit **81**D latches each registration value of the shift register **81**E with the latch signal LT transmitted from the recording head control unit **72**F.

[0086] The gradation decoder **81**C decodes the value (the image data SD') latched by the latch circuit **81**D and the mask control signal MN, to output a logic level voltage signal. The level shifter **81**B performs level conversion on the logic level voltage signal of the gradation decoder **81**C to a level at which the analog switch **81**A can operate.

[0087] The analog switch **81**A is a switch that is turned on and off by the logic level voltage signal of the gradation decoder **81**C that is supplied via the level shifter **81**B. The analog switch **81**A is provided for each of the nozzles of the recording head **12**, and is connected to individual electrodes **153** of the piezoelectric elements **121** corresponding to the respective nozzles. The analog switch **81**A also receives the drive waveform Vcom from the drive waveform generation circuit **77**. Further, the timing of the mask control signal MN is synchronized with the timing of the drive waveform Vcom, as described above.

[0088] Accordingly, the analog switch **81**A switches on/off at an appropriate timing in accordance with the logic level voltage signal of the gradation decoder **81**C supplied via the level shifter **81**B, to select a discharge pulse contained in each pulse unit included in the drive waveform Vcom, for each of the piezoelectric elements **121** corresponding to the respective nozzles. As a result, a voltage having the drive waveform indicated by the pulse unit formed with the selected discharge pulse is applied to the individual electrodes **153** corresponding to the piezoelectric elements **121**, so that the size of the ink droplets to be discharged from the nozzles is controlled.

[0089] Note that the configuration of the liquid discharge apparatus **1** illustrated in FIGS. **5** through **7** is an example, and the liquid discharge apparatus **1** does not necessarily include all the components illustrated in FIGS. **5** through **7**, or may include some other components.

[0090] Drive Waveform

[0091] Next, the drive waveform that the drive waveform generation circuit **77** outputs to the recording head driver **81** is described in detail. Note that the drive waveform that the drive waveform generation circuit **77** outputs to the recording head driver **81** corresponds to the drive waveform Vcom.

[0092] The drive waveform generation circuit **77** generates a drive waveform including a plurality of discharge pulses in a pulse unit of one discharge cycle.

[0093] One discharge cycle is a cycle of a drive waveform to be applied to the piezoelectric elements **121** to discharge one liquid droplet to be discharged from the nozzles **104**. The drive waveform is formed with one or more pulse units. In other words, the waveform in each period after division that divides a drive waveform by one discharge cycle is equivalent to a pulse unit.

[0094] FIG. **8** is a chart illustrating the waveform of a pulse unit Q corresponding to one discharge cycle in a drive waveform W of this embodiment. In FIG. **8**, the abscissa axis indicates time, and the ordinate axis indicates potential. In FIG. **8**, the ordinate axis indicates the potential in a case where a first potential V**1** is illustrated as 100%.

[0095] The pulse unit Q is formed with two discharge pulses P. A discharge pulse waveform P means a pulse of a potential at which liquid droplets can be discharged from the nozzles **104**.

[0096] Specifically, the pulse unit Q is formed with a first discharge pulse waveform P**1**, and a second discharge pulse waveform P**2** after the first discharge pulse waveform P**1**.

[0097] The first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** each have an expansion waveform element E**1** falling from the first potential V**1**, a maintaining waveform element E**2** maintaining a second potential V**2** after the falling, and a contraction waveform element E**3** rising from the maintaining waveform element E**2** toward the first potential V**1**.

[0098] Specifically, the first discharge pulse waveform P**1** is formed with an expansion waveform element E**1**A (a first expansion waveform element), a maintaining waveform element E**2**A, and a contraction waveform element E**3**A (a first contraction waveform element). The second discharge pulse waveform P**2** is formed with an expansion waveform element E**1**B (a first expansion waveform element), a maintaining waveform element E**2**B, and a contraction waveform element E**3**B (a first contraction waveform element).

[0099] The first potential V**1** is a reference potential that serves as the reference, as described above. The first potential V**1** is a potential at which the piezoelectric elements **121** do not contract (are not driven) (no ink droplets are discharged from the nozzles **104**) even when a voltage at the potential is applied to the piezoelectric elements **121**.

[0100] The second potential V**2** is a potential at which pressure is applied to the ink in the liquid chambers **106** by contraction of the piezoelectric elements **121** when a voltage at the potential is applied to the piezoelectric elements **121**, and ink droplets are discharged from the nozzles **104**.

[0101] In other words, a voltage having the waveform indicated by the expansion waveform element E**1** is applied to the piezoelectric elements **121**, so that pressure is applied to the liquid chambers **106** by driving of the piezoelectric elements **121**. A voltage having the waveform indicated by the maintaining waveform element E**2** is then applied to the piezoelectric elements **121**, so that the pressure to the liquid chambers **106** is maintained. A voltage having the waveform indicated by the contraction waveform element E**3** is then applied to the piezoelectric elements **121**, so that the pressure applied to the liquid chambers **106** by the driving of the piezoelectric elements **121** is released. As the voltages represented by the waveforms of a discharge pulse waveform P indicated by the expansion waveform element E**1**, the maintaining waveform element E**2**, and the contraction waveform element E**3** are applied to the piezoelectric elements **121**, ink droplets are discharged from the liquid chambers **106**.

[0102] In this embodiment, the recording head driver **81** (specifically, the analog switch **81**A) corresponding to the selection unit selects one of the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2**, or both the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** as the discharge pulse waveform(s) P included in the pulse unit Q. By doing so, the recording head driver **81** causes the nozzles **104** to discharge different volumes of ink droplets (liquid). In other words, by selecting the discharge pulse waveform(s) P included in the pulse unit Q, the recording head driver **81** separately selects a plurality of types of ink droplets having different volumes, which is to be discharged from the nozzles **104**.

[0103] Specifically, as illustrated in FIG. **8**, to cause the nozzles **104** to discharge a small droplet, the recording head driver **81** selects the first discharge pulse waveform P**1** as the discharge pulse waveform P included in the pulse unit Q. the waveform indicated by the pulse unit Q to be applied to the piezoelectric elements **121** includes the waveform indicated by the first discharge pulse waveform P**1** and, subsequent thereto, the waveform element indicated by the maintaining waveform element maintaining the first potential V**1**.

[0104] To cause the nozzles **104** to discharge medium droplets, the recording head driver **81** selects the second discharge pulse waveform P**2** as the discharge pulse waveform P included in the pulse unit Q. Accordingly, in this case, the waveform indicated by the pulse unit Q to be applied to the piezoelectric elements **121** is obtained by placing the waveform indicated by the second discharge pulse waveform P**2** after the maintaining waveform element maintaining the first potential V**1**.

[0105] Further, to cause the nozzles **104** to discharge large droplets, the recording head driver **81** selects the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** as the discharge pulses P included in the pulse unit Q. Accordingly, in this case, the waveform indicated by the pulse unit Q to be applied to the piezoelectric elements **121** is constructed of the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** immediately thereafter (adjacent thereto).

[0106] A small droplet is liquid having a first volume. A medium droplet is liquid having a second volume that is larger than the first volume. A large droplet is liquid having a third volume that is larger than the second volume.

[0107] In a case where no ink droplets are to be discharged, the recording head driver **81** does not select any discharge pulse waveform P included in the pulse unit Q. In this case, the waveform indicated by the pulse unit Q to be applied to the piezoelectric elements **121** is a waveform formed with a maintaining waveform element that maintains the first potential V**1**.

[0108] A voltage having a drive waveform W represented by a plurality of types of pulse units Q with different volumes of liquid to be discharged, such as large droplets, medium droplets, and small droplets, can be applied to the piezoelectric elements **121**, to cause the respective nozzles **104** to discharge a plurality of types of ink droplets, such as large droplets, medium droplets, and small droplets. Such a case is now described. In this case, there is the need to adjust the pulse units Q of the drive waveform W so that ink droplets discharged from the respective nozzles **104** will land a paper sheet **22** at the same time.

[0109] However, in the pulse unit Q formed with the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** for discharging large droplets, residual vibration caused in the liquid chambers **106** by discharge of ink droplets with the first discharge pulse waveform P**1** may affect the waveform of the second discharge pulse waveform P**2**. In this case, there may be an ink droplet discharge defect, or differences in the arrival time at which ink droplets discharged from the nozzles **104** arrive on the paper sheet **22**.

[0110] For example, if the timing of the second discharge pulse waveform P**2** overlaps with the period of residual vibration caused in the liquid chambers **106** by the first discharge pulse waveform P**1**, resonance with the residual vibration occurs. In this case, due to the resonance between the residual vibration and the second discharge pulse waveform P**2**, the speed of discharge of ink droplets being discharged with the second discharge pulse waveform P**2** may become higher than that in a case where there is no influence of residual vibration.

[0111] On the other hand, in a case where the influence of the residual vibration is similar to antiresonance, the speed of discharge of ink droplets being discharged with the second discharge pulse waveform P**2** becomes lower than that in a case where there is no influence of residual vibration, and a discharge defect or a merge failure may occur.

[0112] Therefore, as illustrated in FIG. **8**, the first discharge pulse waveform P**1** in the pulse unit Q includes a damping element D in this embodiment. A pulse interval T**1** (a first interval) between the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** is in the range of N±⅛ (N being an integer of 1 or greater) to N±¼ of the Helmholtz period of the liquid chambers **106**. In other words, the pulse interval T**1** is in the range of P_{hlm}×(N±⅛) to P_{hlm}×(N±¼), where P_{hlm} represents the Helmholtz period of the liquid chambers **106**.

[0113] The damping element D is represented by a waveform that damps vibration of the ink in the liquid chambers **106**. In other words, the damping element D is represented by a waveform that damps meniscus vibration of the ink.

[0114] For example, as illustrated in FIG. **8**, the damping element D is represented by a waveform in which the potential rises stepwise toward the first potential V**1**, from the start point TA of the rise of the contraction waveform element E**3**A of the first discharge pulse waveform P**1** to the first potential V**1** (see a damping element D**1**). The damping element D**1** is an example of the damping element D.

[0115] The start point TA is the point at which the contraction waveform element E**3**A starts rising toward the first potential V**1** in the first discharge pulse waveform P**1**. Specifically, the start point TA is the point of intersection between the maintaining waveform element E**2**A and the contraction waveform element E**3**A in the first discharge pulse waveform P**1**.

[0116] FIG. **8** illustrates an example in which the damping element D is represented by a waveform that indicates potential rises in two steps: the potential rises from the start point TA at the second potential V**2** toward an intermediate potential V**5**, and, after maintained at the intermediate potential V**5** for a predetermined period of time, the potential rises to the first potential V**1**. The intermediate potential V**5** is a potential between the first potential V**1** and the second potential V**2**. The waveform indicated by the damping element D is not necessarily in two steps, but can be in three or more steps.

[0117] Note that the contraction waveform element E**3**A of the first discharge pulse waveform P**1** preferably includes the damping element D**1**.

[0118] This is because the first discharge pulse waveform P**1** is the discharge pulse waveform P for discharging small droplets, and the second discharge pulse waveform P**2** is the discharge pulse waveform P for discharging the medium droplets. Therefore, if the second potential V**2**, which is the potential of the respective maintaining waveform elements E**2** of the first discharge pulse waveform P**1** and the second discharge pulse waveform P2, is adjusted, there is a possibility that an ink droplet discharge defect will occur.

[0119] That is, as the contraction waveform element E3A of the first discharge pulse waveform P1 includes the damping element D1, the occurrence of a discharge defect can be prevented when ink droplets are discharged by application of the second discharge pulse waveform P2 placed after the first discharge pulse waveform P1.

[0120] Further, as described above, the pulse interval T1 between the first discharge pulse waveform P1 and the second discharge pulse waveform P2 is in the range of N±⅛ (N being an integer of 1 or greater) to N±¼ of the Helmholtz period of the liquid chambers **106**. The Helmholtz period is also referred to as an acoustic natural period in some cases.

[0121] Specifically, the pulse interval T1 indicates the interval from the start point TA of the rise of the contraction waveform element E3A of the first discharge pulse waveform P1 to the start point TB of the rise of the contraction waveform element E3B of the second discharge pulse waveform P2. In other words, the pulse interval T1 indicates the temporal distance from the start point TA to the start point TB. The start point TB of the rise of the contraction waveform element E3B is the point of intersection between the maintaining waveform element E2B and the contraction waveform element E3B in the second discharge pulse waveform P2.

[0122] As the pulse interval T1 between the first discharge pulse waveform P1 and the second discharge pulse waveform P2 is in the range of N±⅛ (N being an integer of 1 or greater) to N±¼ of the Helmholtz period of the liquid chambers **106**, the ink droplets to be discharged with the second discharge pulse waveform P2 can be discharged at a timing close to the timing for causing resonance with the residual vibration caused in the liquid chambers **106** by the first discharge pulse waveform P1.

[0123] The pulse interval T1 can be in the range of N±⅛ (N being an integer of 1 or greater) to N±¼, but is preferably N±⅛ in particular. Further, N can be an integer of 1 or greater, but is preferably an integer in the range of 1 to 3, and is more preferably N=2.

[0124] As the pulse interval T1 is adjusted as described above, it is possible to reduce the possibility of using unintended antiresonance due to variation of the cycles of the individual liquid chambers caused by head variation, as compared with a case where non-resonance is used.

[0125] Further, as the contraction waveform element E3A of the first discharge pulse waveform P1 includes the damping element D1, it is possible to reduce the residual vibration to be caused in the liquid chambers **106** by the first discharge pulse waveform P1.

[0126] Because of this, the speed of discharge of ink droplets being discharged with the second discharge pulse waveform P2 can be prevented from becoming higher due to the resonance between the residual vibration and the second discharge pulse waveform P2 than that in a case where there is no influence of residual vibration. Thus, it is possible to reduce ink droplet discharge defects and discharge speed variation.

[0127] Note that the damping element D can be represented by a waveform that reduces vibration of the ink in the liquid chambers **106**. Therefore, the damping element D is not limited to the damping element D1 represented by a waveform in which the potential rises stepwise toward the first potential V1 from the start point TA of the rise of the contraction waveform element E3A of the first discharge pulse waveform P1 as illustrated in FIG. **8**.

[0128] FIG. **9** is a schematic view illustrating an example of a drive waveform W including some other damping element D. In FIG. **9**, the abscissa axis indicates time, and the ordinate axis indicates potential. In FIG. **9**, the ordinate axis indicates the potential in a case where the first potential V1 is illustrated as 100%.

[0129] A pulse unit Q of a drive waveform W is formed with a first discharge pulse waveform P1 and a second discharge pulse waveform P2 as in the above described example. However, the damping element D included in the contraction waveform element E3A of the first discharge pulse waveform P1 is a damping element D2 represented by a waveform indicated by an impulse wave, as illustrated in FIG. **9**. The damping element D2 is an example of the damping element D.

[0130] Specifically, the damping element D2 is formed with a second expansion waveform element E21 that falls toward a third potential V3, and a second contraction waveform element E23 that rises from the second expansion waveform element E21 toward the first potential V1. However, a second maintaining waveform element E22 that maintains the third potential V3 can be placed between the second expansion waveform element E21 and the second contraction waveform element E23. The third potential V3 is a potential between the first potential V1 and the second potential V2.

[0131] Further, the slope $\alpha 1$ of the second expansion waveform element E21 in the damping element D2 is steeper than the slope $\alpha 2$ of the second contraction waveform element E23 in the damping element D2.

[0132] The potential at the start point TD of the fall of the second expansion waveform element E21 in the damping element D2 is a potential V4 between the first potential V1 and the third potential V3.

[0133] In a case where the damping element D2 illustrated in FIG. **9** is used as the damping element D, a start-point interval T2 (a second interval) between the start point TA of the rise of the contraction waveform element E3A of the first discharge pulse waveform P1 and the start point TC of the rise of the second contraction waveform element E23 in the damping element D2 is preferably equal to or shorter than ¾ of the Helmholtz period of the liquid chambers **106**.

[0134] In other words, the start-point interval T2 indicates the temporal distance from the start point TA of the rise of the contraction waveform element E3A to the start point TC of the rise of the second contraction waveform element E23.

[0135] The start-point interval T2 is preferably equal to or shorter than ¾ of the Helmholtz period of the liquid chambers **106**, but is preferably in the range of ¾ to ¼, or is more preferably in the range of ½ to ¼.

[0136] As described above, the damping element D can be the damping element D2 represented by an impulse waveform formed with the second expansion waveform element E21 and the second contraction waveform element E23. That is, the damping element D can be formed by adjusting the parameters of the impulse waveform.

[0137] As described above, in this embodiment, the drive waveform generation circuit **77** generates the drive waveform W in which a pulse unit Q of one discharge cycle is formed with the first discharge pulse waveform P1 including the damping element D, and the second discharge pulse waveform P2 placed after the first discharge pulse waveform

P1. The pulse interval T1 between the first discharge pulse waveform P1 and the second discharge pulse waveform P2 is in the range of N±⅛ (N being an integer of 1 or greater) to N±¼ of the Helmholtz period of the liquid chambers **106**.

[0138] With this arrangement, the liquid discharge apparatus **1** of this embodiment can generate the drive waveform W for discharging ink droplets of a plurality of types with different volumes, such as large droplets, medium droplets, and small droplets, using the pulse unit Q including the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2**, without the use of any micro-vibration pulse that is used in a related art.

[0139] In a related art, a combination of three discharge pulses is used as a drive waveform for discharging the respective volumes of ink droplets: large droplets, medium droplets, and small droplets.

[0140] FIG. **10** is a chart for explaining a comparative drive waveform W**2**. As illustrated in FIG. **10**, a combination of three discharge pulses P forms a pulse unit for one discharge cycle for discharging the respective volumes of ink droplets: large droplets, medium droplets, and small droplets.

[0141] In this embodiment, on the other hand, as illustrated in FIG. **8** and FIG. **9**, the two discharge pulses P of the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** constitute the pulse unit Q of one discharge cycle for discharging the respective volumes of ink droplets: large droplets, medium droplets, small droplets, and no discharge.

[0142] Therefore, while the length of the drive waveform of one discharge cycle in the drive waveform W is about 30 μm in the comparative configuration illustrated in FIG. **10**, the waveform length of the pulse unit Q of one discharge cycle in the drive waveform W in this embodiment can be about 25 μm, for example.

[0143] Therefore, the liquid discharge apparatus **1** of this embodiment can shorten the length of the drive waveform W.

[0144] Further, the contraction waveform element E**3** of the first discharge pulse waveform P**1** in the pulse unit Q includes the damping element D. As the contraction waveform element E**3** of the first discharge pulse waveform P**1** includes the damping element D, the first discharge pulse waveform P**1**, which is the first pulse for forming large droplets, has a damping effect, while the volume of each small droplet to be discharged with the first discharge pulse waveform P**1** can be reduced. Thus, it is possible to widen the difference in liquid volume between a small droplet to be discharged with the first discharge pulse waveform P**1** and a medium droplet to be discharged with the second discharge pulse waveform P**2**.

[0145] Printing Process to be Performed by the Liquid Discharge Apparatus

[0146] Next, an example of procedures in a printing process to be performed by the control device **90** of the liquid discharge apparatus **1** is described.

[0147] FIG. **11** is a flowchart illustrating an example of procedures in a printing process to be performed by the control device **90**.

[0148] First, the recording head control unit **72**F of the control device **90** receives image data from the image processing circuit **61** (step S**200**).

[0149] The drive waveform generation circuit **77** then generates the drive waveform W based on the image data and the like that have been input in step S**200**, and transmits the drive waveform W to the recording head driver **81** (step S**202**).

[0150] Based on the image data that has been input in step S**200**, the analog switch **81**A of the recording head driver **81** selects, for each pulse unit Q, a discharge pulse waveform P (the first discharge pulse waveform P**1** and/or the second discharge pulse waveform P**2**) included in the drive waveform W supplied from the drive waveform generation circuit **77** (step S**204**). Through the processing in step S**204**, the voltage of the drive waveform W indicated by the pulse unit Q formed with the selected discharge pulse waveform(s) P is applied to the piezoelectric elements **121** (step S**206**). Through this processing, ink droplets having the volume corresponding to the drive waveform W indicated by the pulse unit Q are discharged from the nozzles **104** corresponding to the piezoelectric elements **121**, and printing is performed (step S**208**).

[0151] The control device **90** then determines whether printing of all the image data input from the image processing circuit **61** has been completed (step S**210**). If the printing has been completed (step S**210**: Yes), the printing operation is ended. If the printing has not been completed yet (step S**210**: No), the process returns to step S**200**.

[0152] As described above, the control device **90** according to this embodiment includes the drive waveform generation circuit **77** (the drive waveform generation unit) and the recording head driver **81** (the selection unit). The drive waveform generation circuit **77** generates the drive waveform W including a plurality of discharge pulses P in the pulse unit Q of one discharge cycle, which is to be applied to the piezoelectric elements **121** (electromechanical transducer elements) to change the pressure in the liquid chambers **106** communicating with the nozzles **104** that discharge liquid (ink droplets). The recording head driver **81** (the selection unit) selects a discharge pulse waveform P included in the pulse unit Q in accordance with the volume of the liquid to be discharged. The pulse unit Q is formed with the first discharge pulse waveform P**1** including the damping element D that damps vibration of ink (liquid), and the second discharge pulse waveform P**2** placed after the first discharge pulse waveform P**1**. The pulse interval T**1** between the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** is in the range of N±⅛ (N being an integer of 1 or greater) to N±¼ of the Helmholtz period of the liquid chambers **106**. The recording head driver **81** (the selection unit) selects the first discharge pulse waveform P**1**, the second discharge pulse waveform P**2**, or the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** as the discharge pulse waveform(s) P included in the pulse unit Q. By doing so, the recording head driver **81** causes the nozzles **104** to discharge different volumes of ink droplets (liquid).

[0153] As described above, in the control device **90** according to this embodiment, the first discharge pulse waveform P**1**, the second discharge pulse waveform P**2**, or the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** in the pulse unit Q formed with the first discharge pulse waveform P**1** including the damping element D and the second discharge pulse waveform P**2** are selected, to cause the nozzles **104** to discharge different volumes of liquid.

[0154] Thus, the length of the drive waveform W can be made shorter than that in a related art by which a micro-vibration pulse is separately added, and that in a related art by which a combination of three discharge pulses is used to discharge different volumes of liquid. Accordingly, the control device **90** of this embodiment can shorten the length of the drive waveform W.

[0155] Further, as the control device **90** of this embodiment can shorten the length of the drive waveform W, high-frequency driving of the recording head **12** with the drive waveform W of a short wavelength can be performed.

[0156] The control device **90** according to this embodiment can also reduce differences in the landing position between liquid droplets with different volumes to be discharged in conjunction with the discharge speed during the time from the discharge to the arrival on a paper sheet **22**, and the decrease in the roundness of ink droplets that have arrived on the paper sheet **22** due to a large droplet merge failure.

[0157] Further, the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** each have the expansion waveform element E**1** falling from the first potential V**1**, the maintaining waveform element E**2** maintaining the second potential V**2** after the falling, and the contraction waveform element E**3** rising from the maintaining waveform element E**2** toward the first potential V**1**. The contraction waveform element E**3** of the first discharge pulse waveform P**1** includes the damping element D.

[0158] The pulse interval T**1** indicates the interval from the start point TA of the rise of the contraction waveform element E**3**A of the first discharge pulse waveform P**1** to the start point TB of the rise of the contraction waveform element E3B of the second discharge pulse waveform P**2**.

[0159] The damping element D**1** is represented by a waveform in which the potential rises stepwise toward the first potential V**1** from the start point TA of the rise of the contraction waveform element E**3**A of the first discharge pulse waveform P**1**.

[0160] Further, the damping element D**2** is formed with the second expansion waveform element E**21** that falls toward the third potential V**3** between the first potential V**1** and the second potential V**2**, and the second contraction waveform element E**23** that rises from the second expansion waveform element E**21** toward the first potential V**1**, and the slope α**1** of the second expansion waveform element E**21** is steeper than the slope α**2** of the second contraction waveform element E**23**.

[0161] The start-point interval T**2** between the start point TA of the rise of the contraction waveform element E**3**A of the first discharge pulse waveform P**1** and the start point TC of the rise of the second contraction waveform element E**23** in the damping element D**2** is preferably equal to or shorter than ¾ of the Helmholtz period of the liquid chambers **106**.

[0162] The recording head driver **81** (the selection unit) selects the first discharge pulse waveform P**1** to cause the nozzles **104** to discharge the first volume of liquid, selects the second discharge pulse waveform P**2** to cause the nozzles **104** to discharge the second volume of liquid that is larger than the first volume, and selects the first discharge pulse waveform P**1** and the second discharge pulse waveform P**2** to cause the nozzles **104** to discharge the third volume of liquid that is larger than the second volume.

[0163] The liquid discharge apparatus **1** of this embodiment includes: the nozzles **104** that discharge liquid (ink droplets); the piezoelectric elements **121** (electromechanical transducer elements) that change the pressure in the liquid chambers **106** communicating with the nozzles **104**; the drive waveform generation circuit **77** (the drive waveform generation unit) that generates the drive waveform W including a plurality of discharge pulses P in the pulse unit Q of one discharge cycle to be applied to the piezoelectric elements **121**; and the recording head driver **81** (the selection unit) that selects a discharge pulse waveform P included in the pulse unit Q in accordance with the volume of liquid to be discharged.

[0164] Note that the recording head **12** in this embodiment is a functional component that discharges/ejects liquid from the nozzles **104**.

[0165] Liquid to be discharged from the nozzles **104** of the head is not limited to a particular liquid as long as the liquid has a viscosity or surface tension to be discharged from the head. However, preferably, the viscosity of the liquid is not greater than 30 mPa·s under ordinary temperature and ordinary pressure or by heating or cooling. Examples of the liquid include a solution, a suspension, or an emulsion including, for example, a solvent, such as water or an organic solvent, a colorant, such as dye or pigment, a functional material, such as a polymerizable compound, a resin, a surfactant, a biocompatible material, such as DNA, amino acid, protein, or calcium, and an edible material, such as a natural colorant. Such a solution, a suspension, or an emulsion can be used for, e.g., inkjet ink, surface treatment liquid, a liquid for forming components of electronic element or light-emitting element or a resist pattern of electronic circuit, or a material solution for three-dimensional fabrication.

[0166] The piezoelectric elements **121** are an example of electromechanical transducer elements as described above. The piezoelectric element **121** is an energy generation source for liquid discharge. Examples of the energy generation source include a piezoelectric actuator (a laminated piezoelectric element or a thin-film piezoelectric element), a thermal actuator that employs an electrothermal transducer element, such as a heat element, and an electrostatic actuator including a diaphragm and opposed electrodes.

[0167] The liquid discharge apparatus **1** can be any apparatus that includes the recording head **12** and drives the recording head **12** to discharge liquid. The liquid discharge apparatus **1** includes, in addition to apparatuses to discharge liquid to materials to which the liquid can adhere, apparatuses to discharge the liquid into gas (air) or liquid.

[0168] The liquid discharge apparatus **1** can also include devices to feed, convey, and discharge the material onto which liquid adheres. The liquid discharge apparatus can further include a pretreatment apparatus to apply treatment liquid to the material before liquid is discharged onto the material and a post-treatment apparatus to apply treatment liquid to the material after liquid is discharged onto the material.

[0169] The liquid discharge apparatus **1** is not limited to the configuration to apply liquid droplets onto the paper sheet **22**, to form an image. For example, the liquid discharge apparatus **1** can be an inkjet three-dimensional fabricating apparatus. In this case, for example, the liquid discharge apparatus **1** is a three-dimensional fabricating apparatus (a solid fabricating apparatus) that discharges a fabricating liquid onto layers of powder, in order to fabricate a three-dimensional object (three-dimensional fabricated object). Moreover, the liquid discharge apparatus **1** can be a three-dimensional fabricating apparatus that discharges a fabricating liquid for fabricating a three-dimensional modeled object and forms the modeled object by discharging the fabricating liquid so as to be laminated.

[0170] The liquid discharge apparatus **1** is not limited to an apparatus to discharge liquid to visualize meaningful images, such as letters or figures. For example, the liquid discharge apparatus can be an apparatus to form meaningless images, such as meaningless patterns, or fabricate meaningless three-dimensional images.

[0171] The "liquid adherable material" is a material on which a liquid can be attached at least temporarily, and indicates a material on which a liquid is adhered and fixed, adhered and permeated, and the like. Examples of "material to which liquid can adhere" include paper sheets, recording media such as recording sheet, recording sheets, film, and cloth; electronic components such as electronic substrates and piezoelectric elements; and media such as powder layers, organ models, and testing cells. The term "material to which liquid can adhere" includes any material to which liquid adheres, unless particularly limited.

[0172] Examples of the "material on which liquid can be adhered" include any materials on which liquid can be adhered even temporarily, such as paper, thread, fiber, fabric, leather, metal, plastic, glass, wood, and ceramic.

[0173] The liquid discharge apparatus **1** can be an apparatus to relatively move the recording head **12** and a material on which liquid can be adhered. However, the liquid discharge apparatus is not limited to such an apparatus. As a specific example, the liquid discharge apparatus **1** can be a serial type apparatus that moves the recording head **12**, a line type apparatus that does not move the recording head **12**, or the like.

[0174] Examples of the liquid discharge apparatus **1** further include a treatment liquid coating apparatus to discharge a treatment liquid to the paper sheet **22** to coat, with the treatment liquid, a sheet surface to reform the sheet surface and an injection granulation apparatus in which a composition liquid including raw materials dispersed in a solution is discharged through nozzles to granulate fine particles of the raw materials.

[0175] Although some embodiments of the present disclosure have been described above, the above-described embodiments are presented as examples and are not intended to limit the scope of the present invention. The above-described embodiments can be implemented in other various forms, and various omissions, replacements, and changes can be made without departing from the scope of the invention. These embodiments and modifications thereof are included in the scope and gist of the invention, and are included in the invention described in the claims and the equivalent scope thereof.

[0176] The operation by each apparatus or terminal constituting the liquid discharge apparatus **1** according to the embodiments described above can be implemented in any convenient form, for example using hardware, software, or a mixture of hardware and software.

[0177] For executing a process or processes using software, a program storing a processing sequence installed in a memory of a computer embedded in a dedicated hardware is executed. Alternatively, such program can be installed for execution in a memory of a general purpose computer that can perform various processes.

[0178] The program can be stored in advance in a hard disc or a read only memory (ROM) as a recording medium. Alternatively, the program can be stored temporarily or permanently stored in a removable recording medium. Such removable recording medium can be provided as a packaged software. Such removable recording medium can be implemented by various types of a recording medium such as a magnetic disk or a semiconductor memory.

[0179] The program can be installed in a computer from the removable recording medium as described above. Alternatively, the program can be download from a website to the computer via a wireless communications network. Alternatively, the program may be transferred to the computer via a wired communications network.

[0180] Each device constituting the liquid discharge apparatus **1** according to the embodiments described above may execute each step of the operation according to the exemplary embodiments described above sequentially, concurrently or individually depending on performance of the apparatus or terminal or as needed. For example, according to the processing capability of the device that executes the processing or depending on the necessity, the device can be configured to execute the processing in parallel or individually.

[0181] The above-described embodiments are illustrative and do not limit the present invention. Thus, numerous additional modifications and variations are possible in light of the above teachings. For example, elements and/or features of different illustrative embodiments may be combined with each other and/or substituted for each other within the scope of the present invention.

[0182] Any one of the above-described operations may be performed in various other ways, for example, in an order different from the one described above.

[0183] Each of the functions of the described embodiments may be implemented by one or more processing circuits or circuitry. Processing circuitry includes a programmed processor, as a processor includes circuitry. A processing circuit also includes devices such as an application specific integrated circuit (ASIC), digital signal processor (DSP), field programmable gate array (FPGA), and comparative circuit components arranged to perform the recited functions.

What is claimed is:

1. A control device comprising:

circuitry configured to:

generate a drive waveform to be applied to an electromechanical transducer element configured to change a pressure in a liquid chamber communicating with a nozzle configured to discharge a liquid, the drive waveform including, in a pulse unit of one discharge cycle:

a first discharge pulse waveform including a damping element configured to damp a vibration of the liquid; and

a second discharge pulse waveform subsequent to the first discharge pulse waveform,

the second discharge pulse waveform being at a pulse interval from the first discharge pulse waveform, the pulse interval in a range of $P_{hlm}\times(N\pm 1/8)$ to $P_{hlm}\times(N\pm 1/4)$, where P_{hlm} represents a Helmholtz period of the liquid chamber and N represents an integer of 1 or greater; and

select at least one of the first discharge pulse waveform and the second discharge pulse waveform in the pulse unit in accordance with a volume of the liquid to be discharged, to cause the nozzle to discharge different volumes of the liquid.

2. The control device according to claim **1**,

wherein each of the first discharge pulse waveform and the second discharge pulse waveform includes:

an expansion waveform element falling from a first potential to a second potential lower than the first potential;

a maintaining waveform element maintaining the second potential; and

a contraction waveform element rising from the maintaining waveform element toward the first potential, and

wherein the contraction waveform element of the first discharge pulse waveform includes the damping element.

3. The control device according to claim **2**,

wherein the pulse interval is an interval from a rise start point of the contraction waveform element of the first discharge pulse waveform to a rise start point of the contraction waveform element of the second discharge pulse waveform.

4. The control device according to claim **2**,

wherein the damping element is a waveform in which a potential rises stepwise from a rise start point of the contraction waveform element of the first discharge pulse waveform toward the first potential.

5. The control device according to claim **2**,

wherein the expansion waveform element of each of the first discharge pulse waveform and the second discharge pulse waveform is referred to as a first expansion waveform element,

wherein the contraction waveform element of each of the first discharge pulse waveform and the second discharge pulse waveform is referred to as a first contraction waveform element,

wherein the damping element includes:

a second expansion waveform element falling toward a third potential between the first potential and the second potential; and

a second contraction waveform element rising from the second expansion waveform element toward the first potential, and

wherein a slope of the second expansion waveform element is steeper than a slope of the second contraction waveform element.

6. The control device according to claim **5**,

wherein a start-point interval between a rise start point of the contraction waveform element of the first discharge pulse waveform and a rise start point of the second contraction waveform element in the damping element is not longer than ¾ of the Helmholtz period of the liquid chamber.

7. The control device according to claim **1**,

wherein the circuitry is configured to:

select the first discharge pulse waveform to cause the nozzle to discharge a first volume of the liquid,

select the second discharge pulse waveform to cause the nozzle to discharge a second volume of the liquid, the second volume being larger than the first volume, and

select the first discharge pulse waveform and the second discharge pulse waveform to cause the nozzle to discharge a third volume of the liquid, the third volume being larger than the second volume.

8. A liquid discharge apparatus comprising:

a nozzle configured to discharge a liquid;

a liquid chamber communicating with the nozzle;

an electromechanical transducer element configured to change a pressure in the liquid chamber; and

circuitry configured to:

generate a drive waveform to be applied to the electromechanical transducer element, the drive waveform including, in a pulse unit of one discharge cycle:

a first discharge pulse waveform including a damping element configured to damp a vibration of the liquid; and

a second discharge pulse waveform subsequent to the first discharge pulse waveform,

the second discharge pulse waveform at a pulse interval from the first discharge pulse waveform, the pulse interval in a range of $P_{hlm}\times(N\pm 1/8)$ to $P_{hlm}\times(N\pm 1/4)$, where P_{hlm} represents a Helmholtz period of the liquid chamber and N represents an integer of 1 or greater; and

select at least one of the first discharge pulse waveform and the second discharge pulse waveform in the pulse unit in accordance with a volume of the liquid to be discharged, to cause the nozzle to discharge different volumes of the liquid.

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