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Watanabe et al.

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(45) **Date of Patent: Aug. 19, 2025**

(54) **LIQUID DISCHARGE APPARATUS, NON-TRANSITORY COMPUTER-EXECUTABLE MEDIUM, AND METHOD FOR CONTROLLING DRIVING OF LIQUID DISCHARGE HEAD**

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B41J 2/135 (2006.01)

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CPC ***B41J 2/04588*** (2013.01); ***B41J 2/04573*** (2013.01); ***B41J 2/135*** (2013.01)

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CPC B41J 2/04573; B41J 2/04581; B41J 2/04588; B41J 2/04593; B41J 2/04596; B41J 2/14274; B41J 2002/14403; B41J 2/04516; B41J 2/04541
See application file for complete search history.

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(57) **ABSTRACT**

A liquid discharge apparatus includes a liquid discharge head and a head drive controller to output a drive waveform including one pulse or two or more pulses selected according to a droplet size. In a case that the drive waveform includes the two or more pulses, the drive waveform includes a final pulse at an end of the two or more pulses. The final pulse includes a first expansion waveform, a first contraction waveform element, a second expansion waveform element, a second contraction waveform element, and a third expansion waveform element. A time period from a start of the first contraction waveform element to a start of the second expansion waveform element is less than 0.5 Tc. A time period from the start of the first contraction waveform element to a start of the second contraction waveform element is within a range from 0.5 Tc to 0.6 Tc.

7 Claims, 16 Drawing Sheets

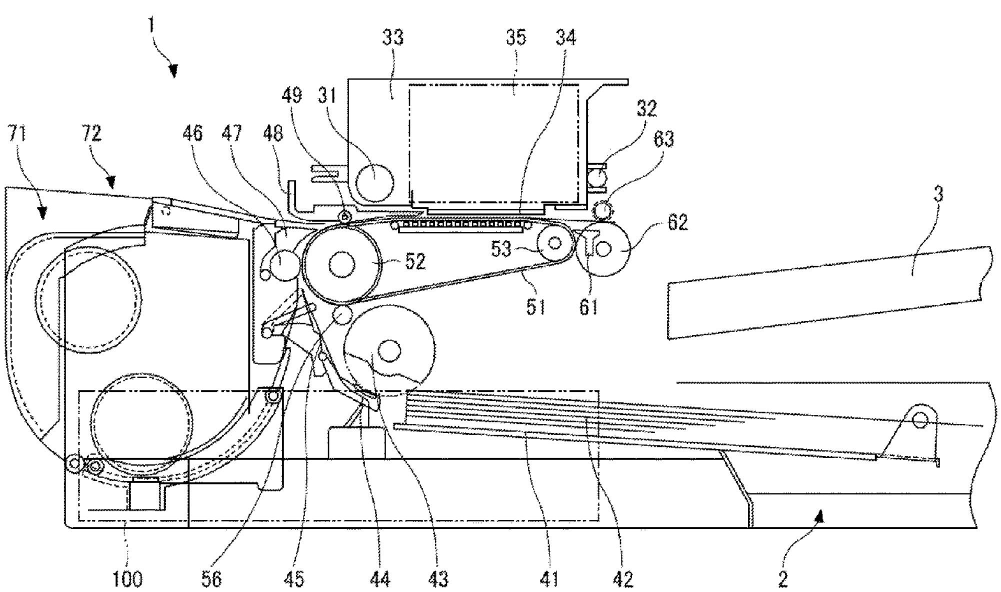

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FIG. 1

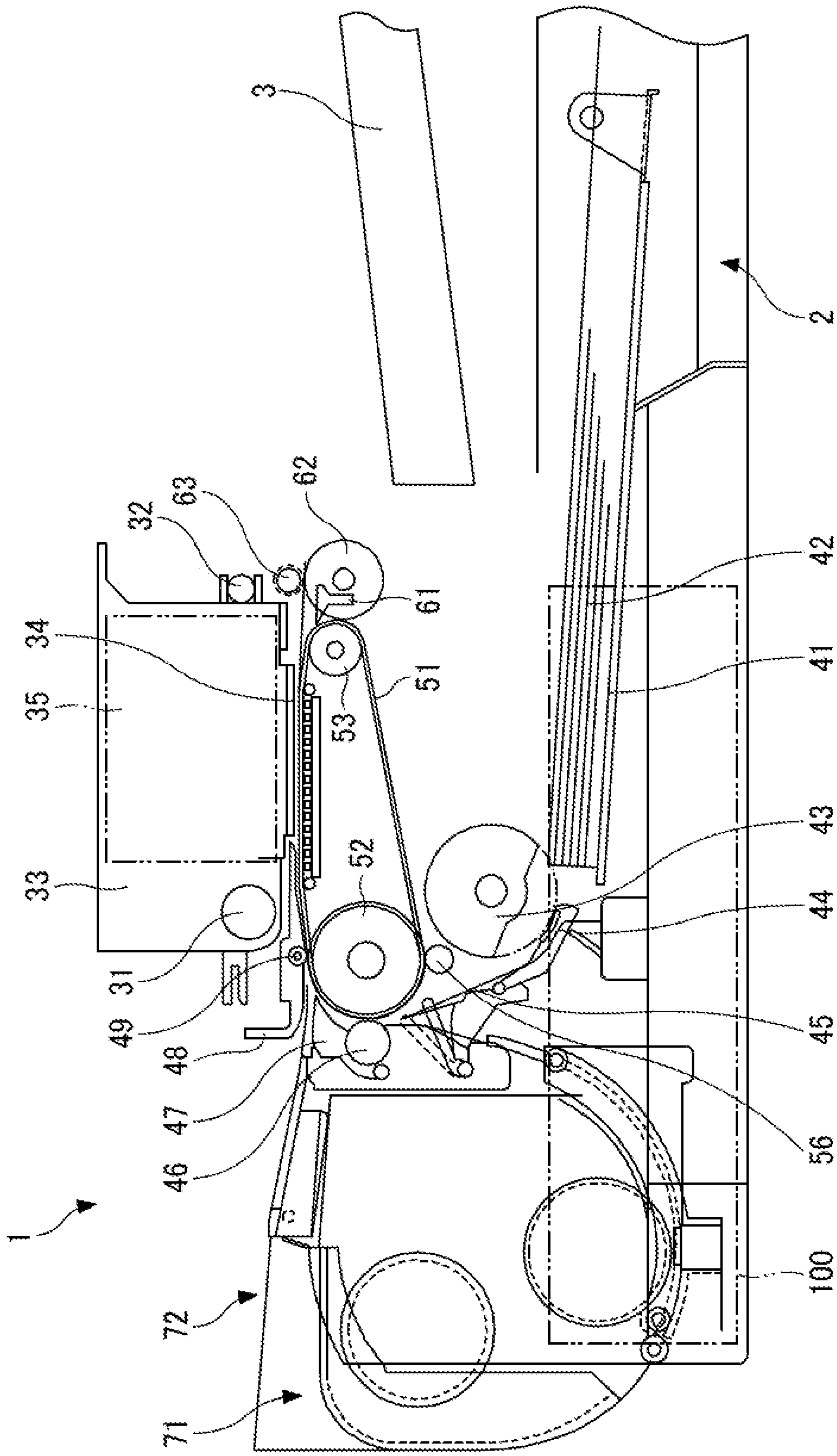
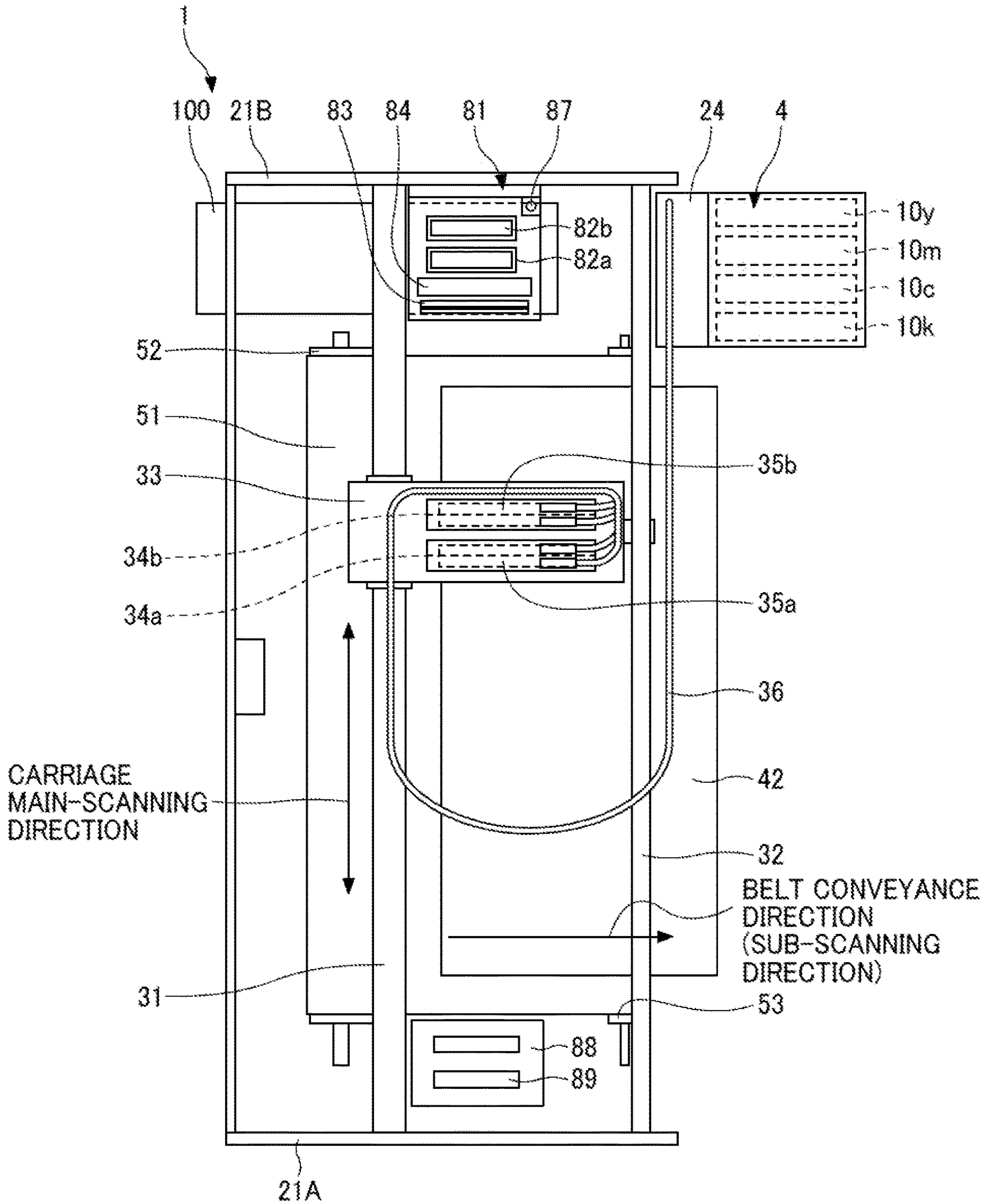

3
2
62
63
32
61
42
41
34
35
53
51
33
52
43
44
31
49
48
47
46
45
56
1
72
71
100

FIG. 2



1
100
21B
83
84
81
87
24
4
82b
82a
10y
10m
10c
10k
52
51
33
34b
34a
35b
35a
36
42
32
CARRIAGE MAIN-SCANNING DIRECTION
BELT CONVEYANCE DIRECTION (SUB-SCANNING DIRECTION)
31
53
88
89
21A

FIG. 3

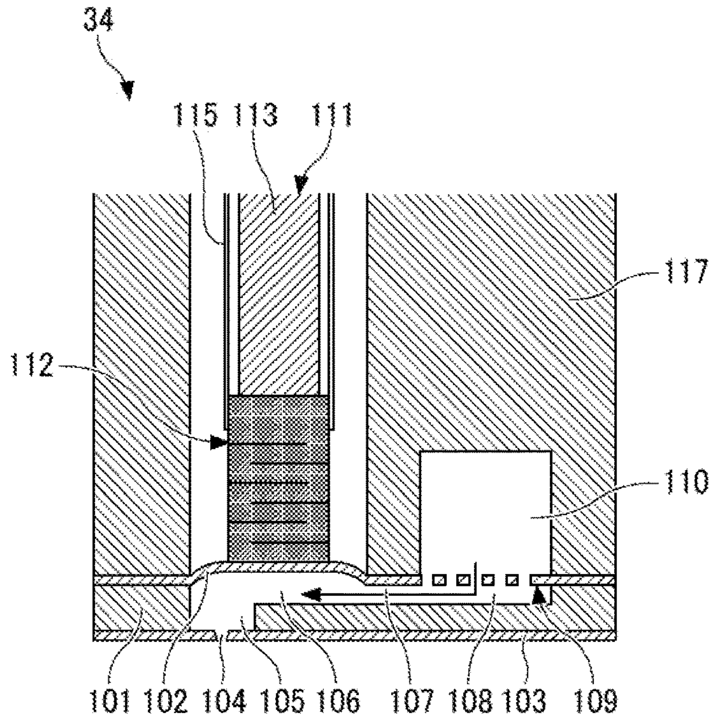

34
115 113 111
117
112
110
101 102 104 105 106 107 108 103 109

FIG. 4

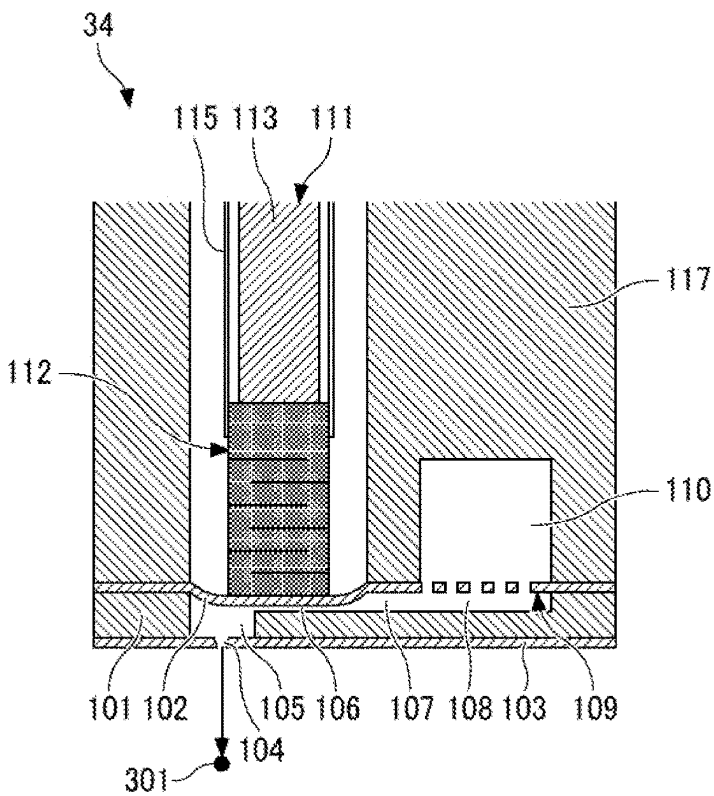
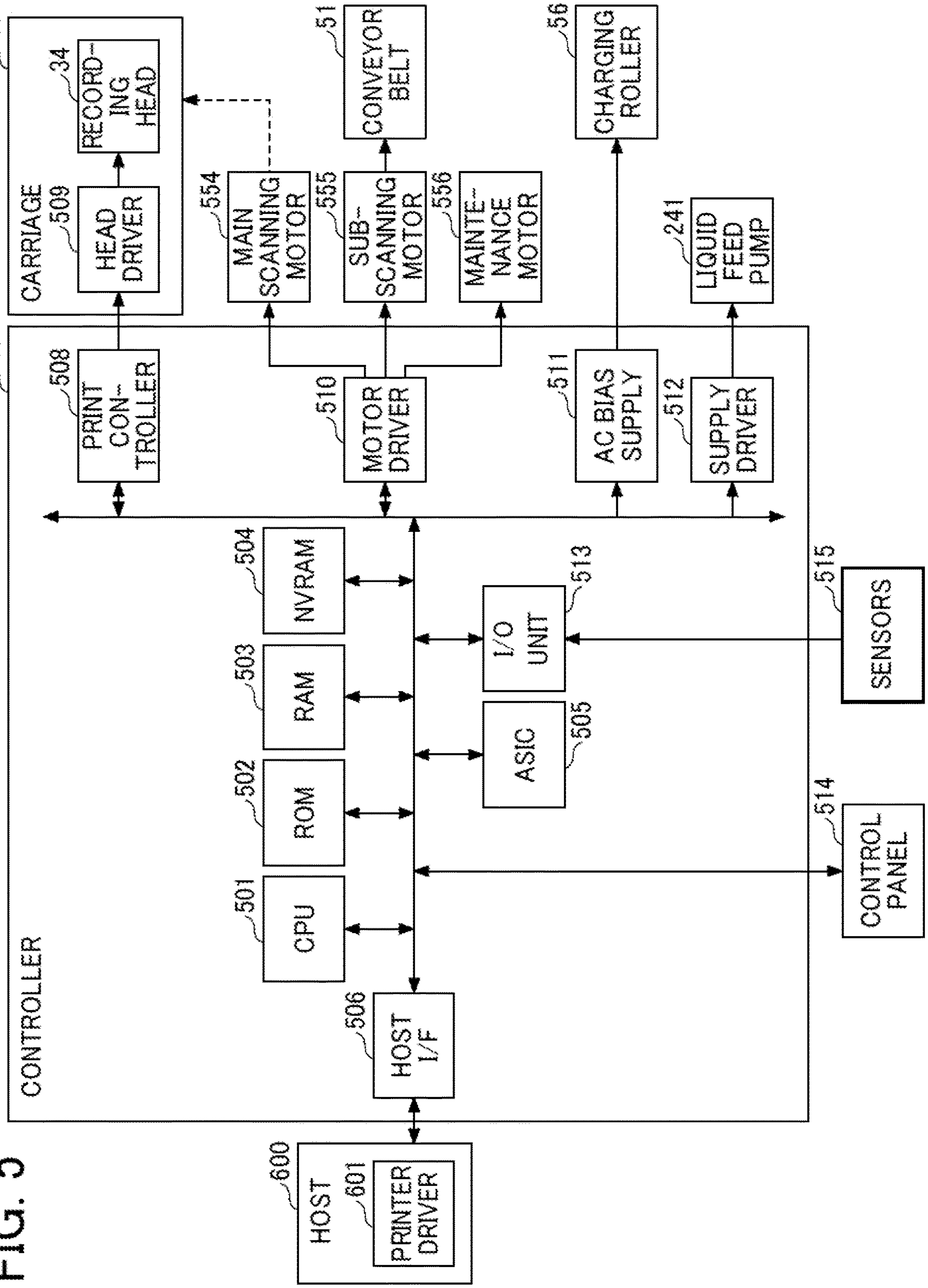

34
115 113 111
117
112
110
101 102 105 106 107 108 103 109
104
301

FIG. 5



CONTROLLER
500
CARRIAGE
33
HEAD DRIVER
509
RECORD-ING HEAD
34
PRINT CON-TROLLER
508
MAIN SCANNING MOTOR
554
SUB-SCANNING MOTOR
555
MAINTE-NANCE MOTOR
556
CONVEYOR BELT
51
MOTOR DRIVER
510
AC BIAS SUPPLY
511
CHARGING ROLLER
56
SUPPLY DRIVER
512
LIQUID FEED PUMP
241
NVRAM
504
RAM
503
ROM
502
CPU
501
I/O UNIT
513
ASIC
505
SENSORS
515
CONTROL PANEL
514
HOST I/F
506
HOST
600
PRINTER DRIVER
601

FIG. 6

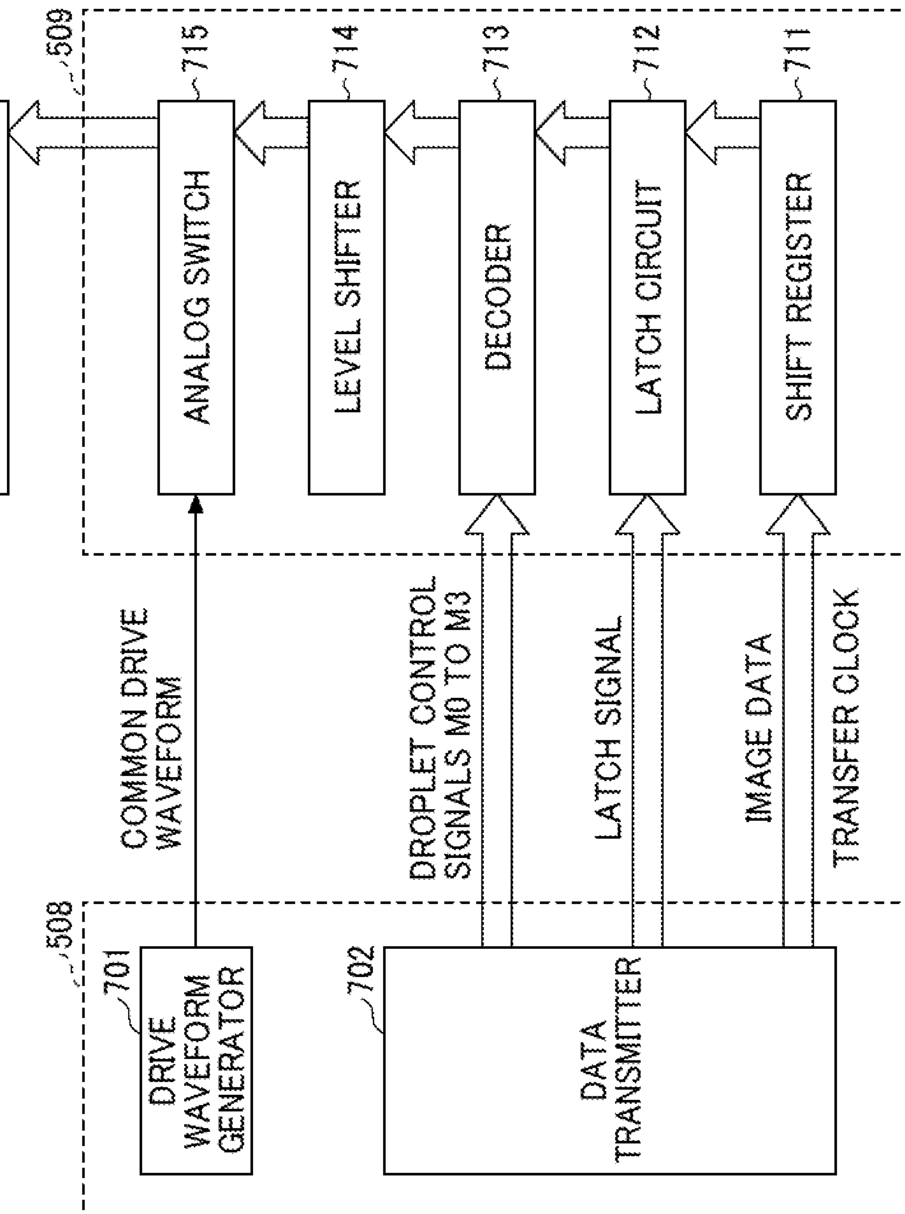

PIEZOELECTRIC MEMBER
112
509
ANALOG SWITCH
715
LEVEL SHIFTER
714
DECODER
713
LATCH CIRCUIT
712
SHIFT REGISTER
711
COMMON DRIVE WAVEFORM
DROPLET CONTROL SIGNALS M0 TO M3
LATCH SIGNAL
IMAGE DATA
TRANSFER CLOCK
508
701
DRIVE WAVEFORM GENERATOR
702
DATA TRANSMITTER

FIG. 7

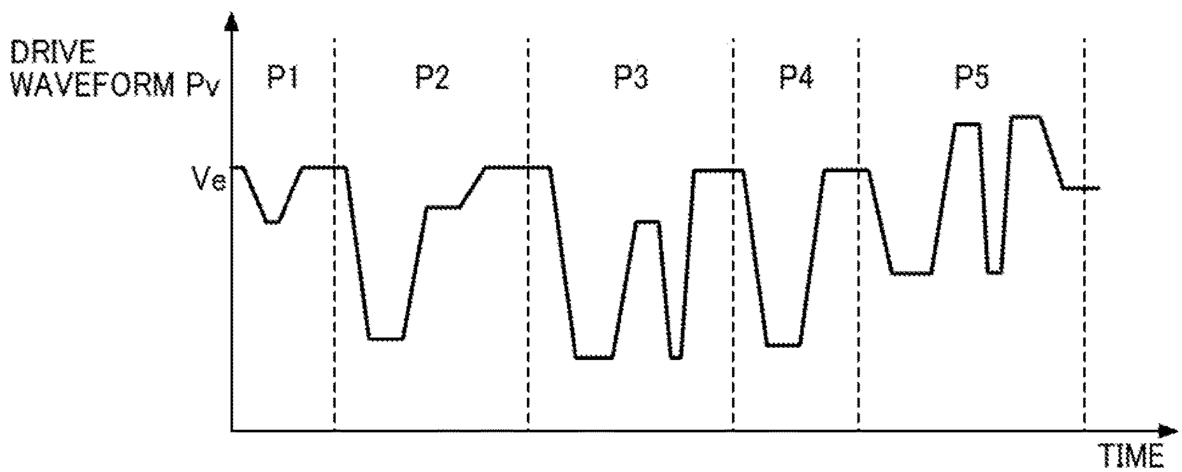


FIG. 8

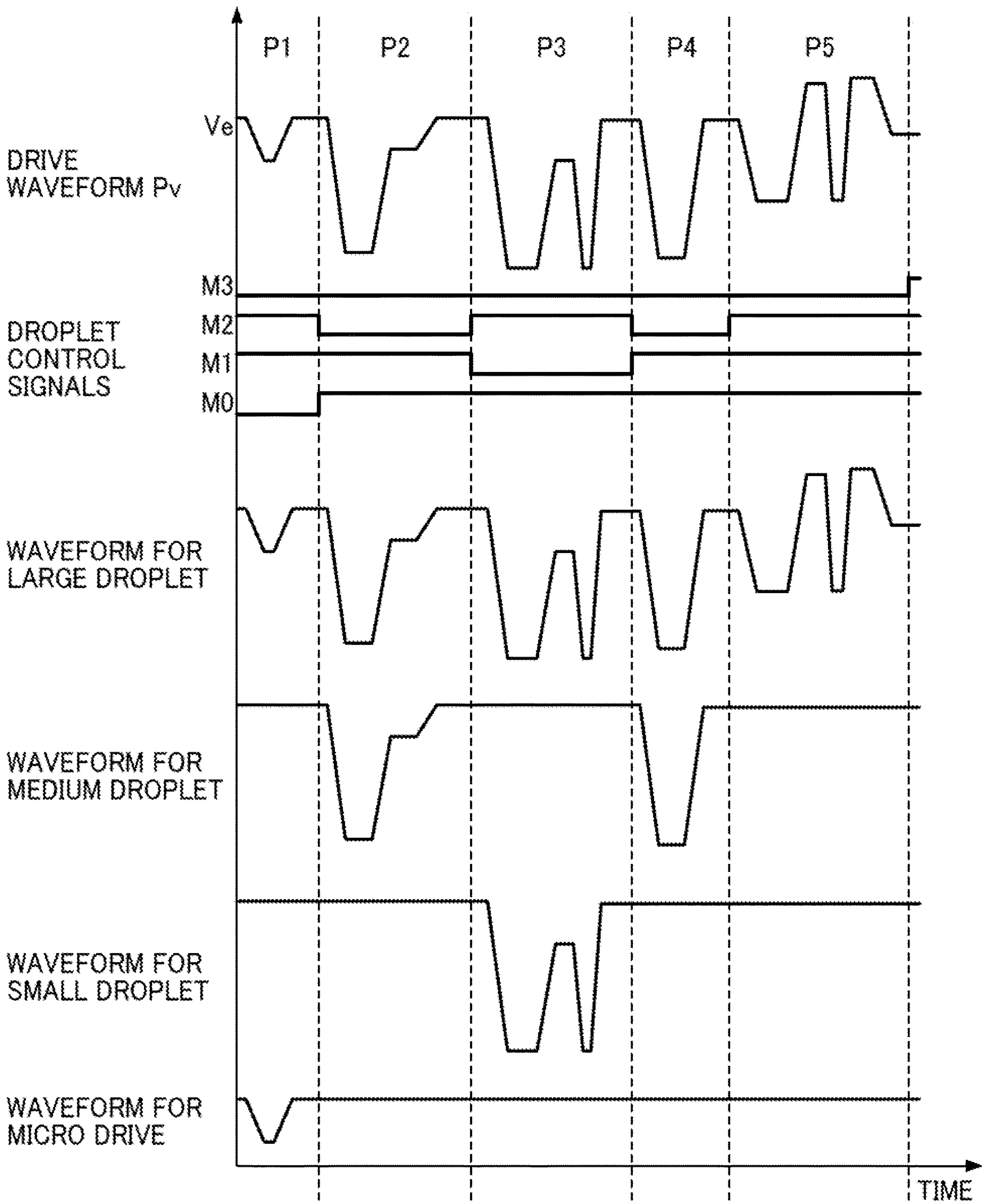

P1
P2
P3
P4
P5
Ve
DRIVE WAVEFORM Pv
M3
M2
M1
M0
DROPLET CONTROL SIGNALS
WAVEFORM FOR LARGE DROPLET
WAVEFORM FOR MEDIUM DROPLET
WAVEFORM FOR SMALL DROPLET
WAVEFORM FOR MICRO DRIVE
TIME

FIG. 9

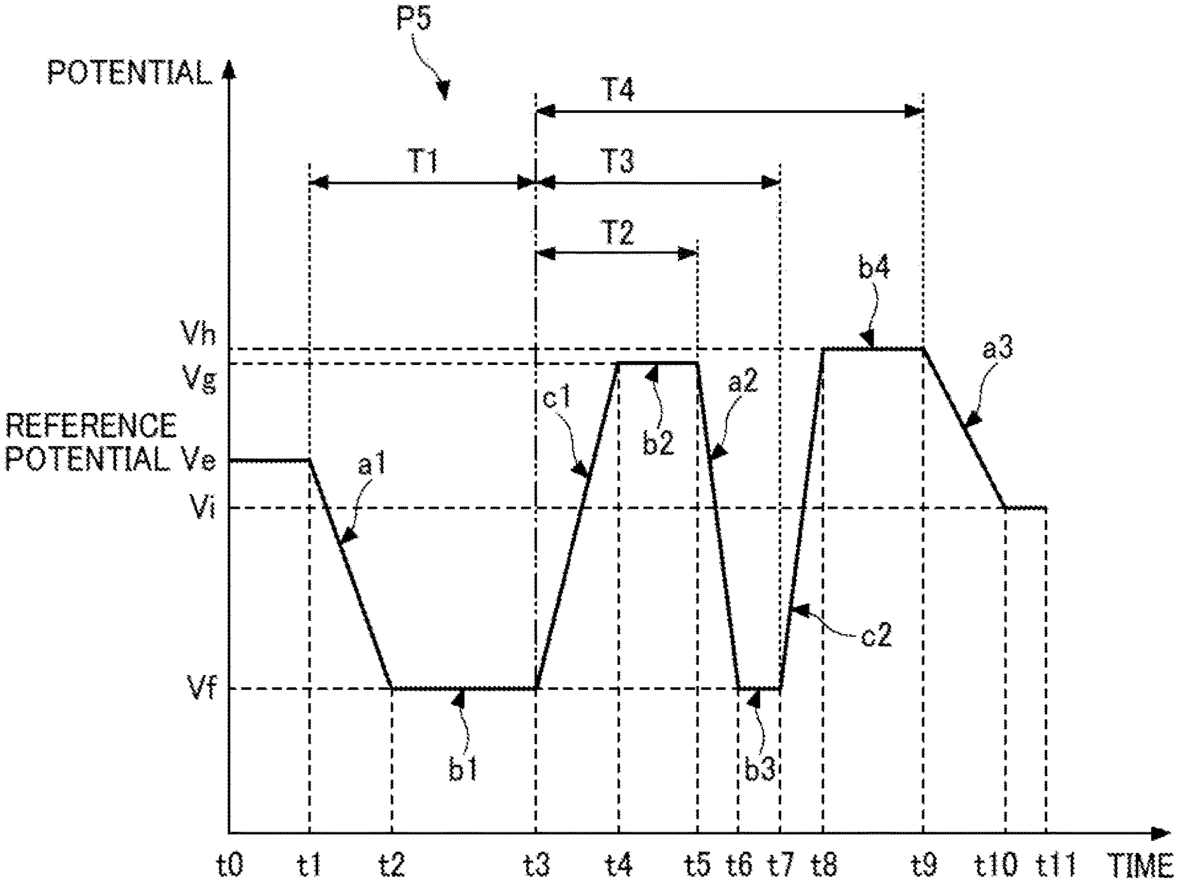

P5
POTENTIAL
T4
T1
T3
T2
b4
Vh
a3
Vg
c1
a2
REFERENCE POTENTIAL Ve
b2
a1
Vi
c2
Vf
b1
b3
t0
t1
t2
t3
t4
t5
t6
t7
t8
t9
t10
t11
TIME

FIG. 10A

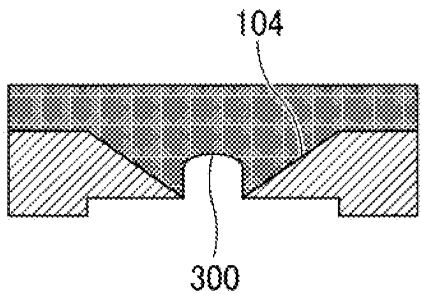


FIG. 10B

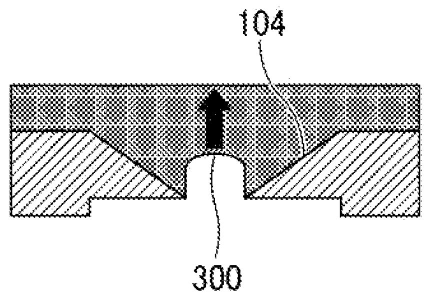


FIG. 10C

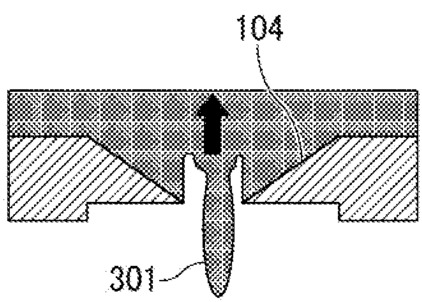


FIG. 10D

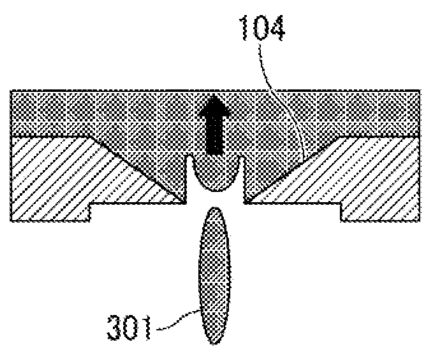


FIG. 11

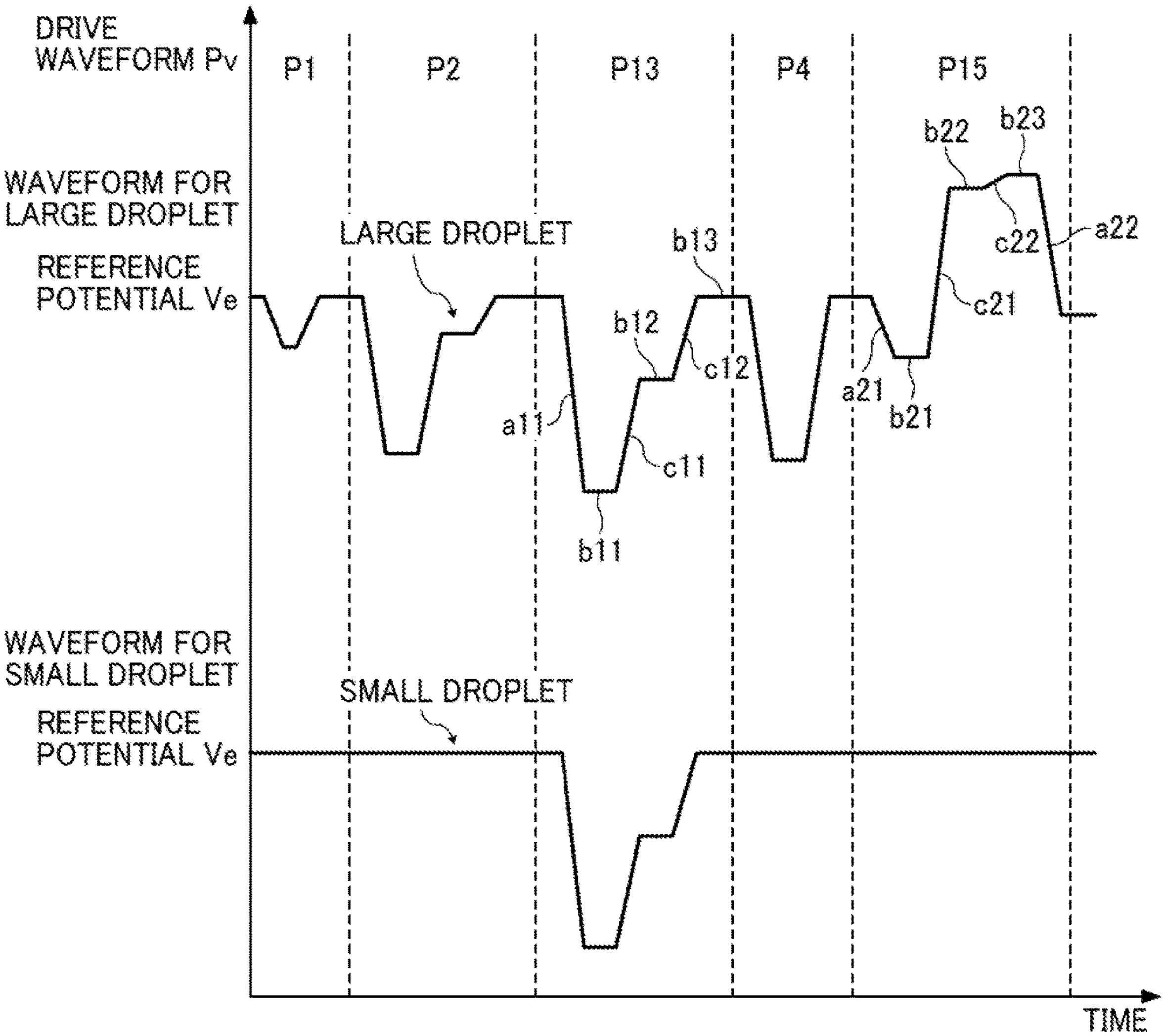

DRIVE WAVEFORM Pv
P1
P2
P13
P4
P15
WAVEFORM FOR LARGE DROPLET
LARGE DROPLET
REFERENCE POTENTIAL Ve
b22
b23
c22
a22
c21
b13
b12
c12
a21
b21
a11
c11
b11
WAVEFORM FOR SMALL DROPLET
SMALL DROPLET
REFERENCE POTENTIAL Ve
TIME

FIG. 12

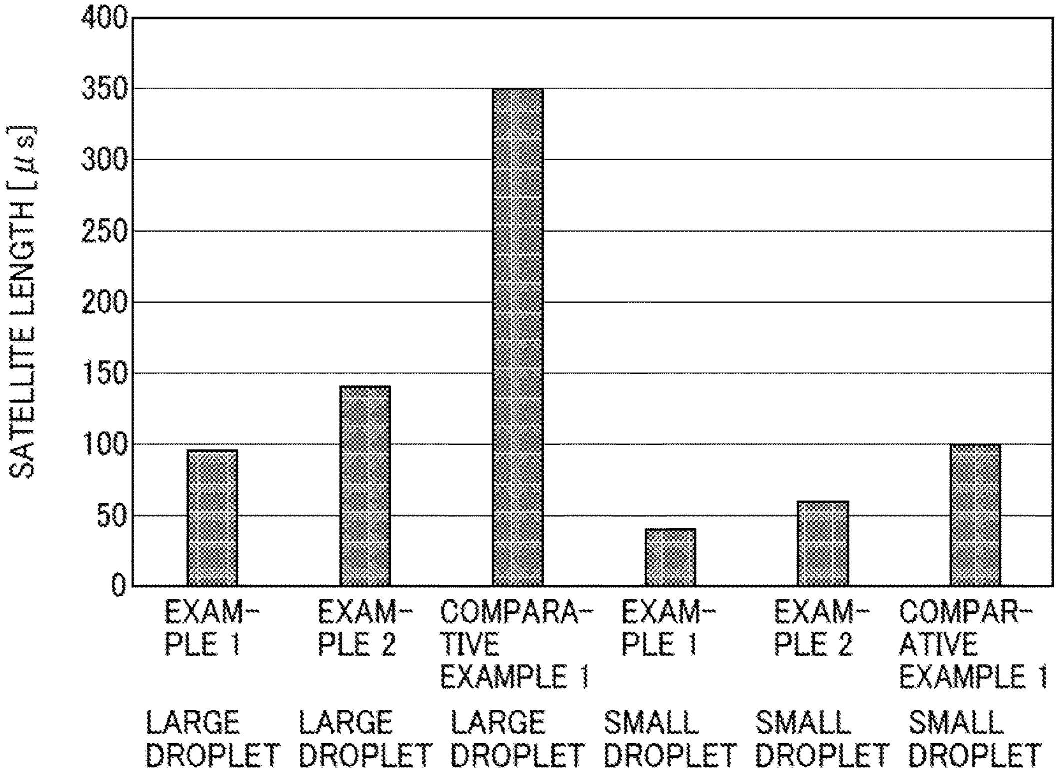

SATELLITE LENGTH [μs]
400
350
300
250
200
150
100
50
0
EXAM-PLE 1
EXAM-PLE 2
COMPARA-TIVE EXAMPLE 1
EXAM-PLE 1
EXAM-PLE 2
COMPAR-ATIVE EXAMPLE 1
LARGE DROPLET
LARGE DROPLET
LARGE DROPLET
SMALL DROPLET
SMALL DROPLET
SMALL DROPLET

FIG. 13

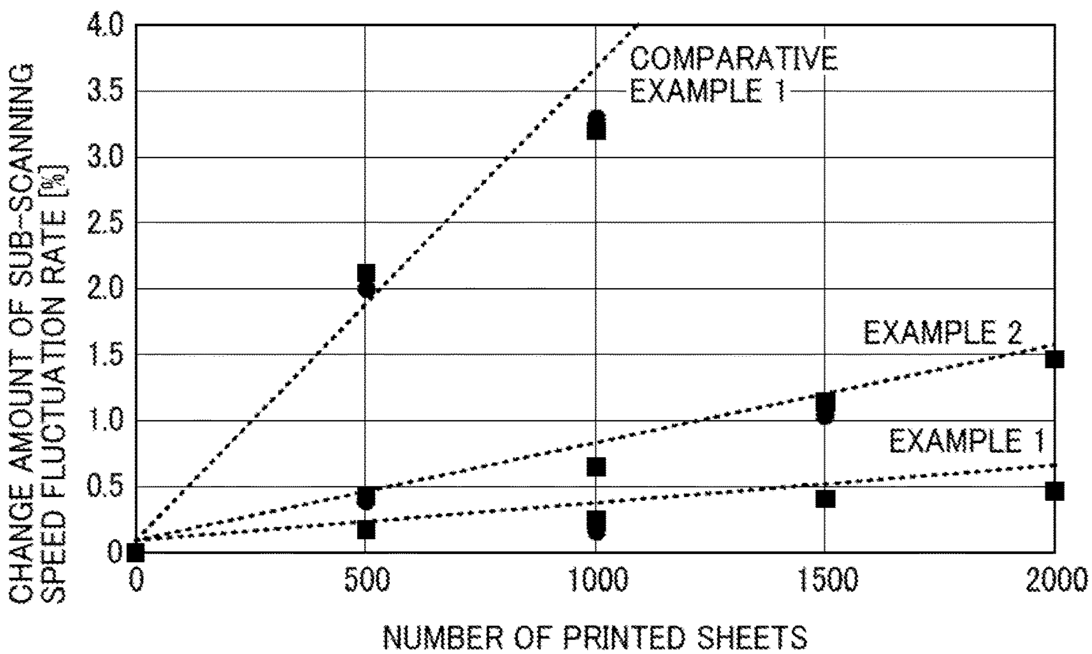

CHANGE AMOUNT OF SUB-SCANNING SPEED FLUCTUATION RATE [%]
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
COMPARATIVE EXAMPLE 1
EXAMPLE 2
EXAMPLE 1
0
500
1000
1500
2000
NUMBER OF PRINTED SHEETS

FIG. 14

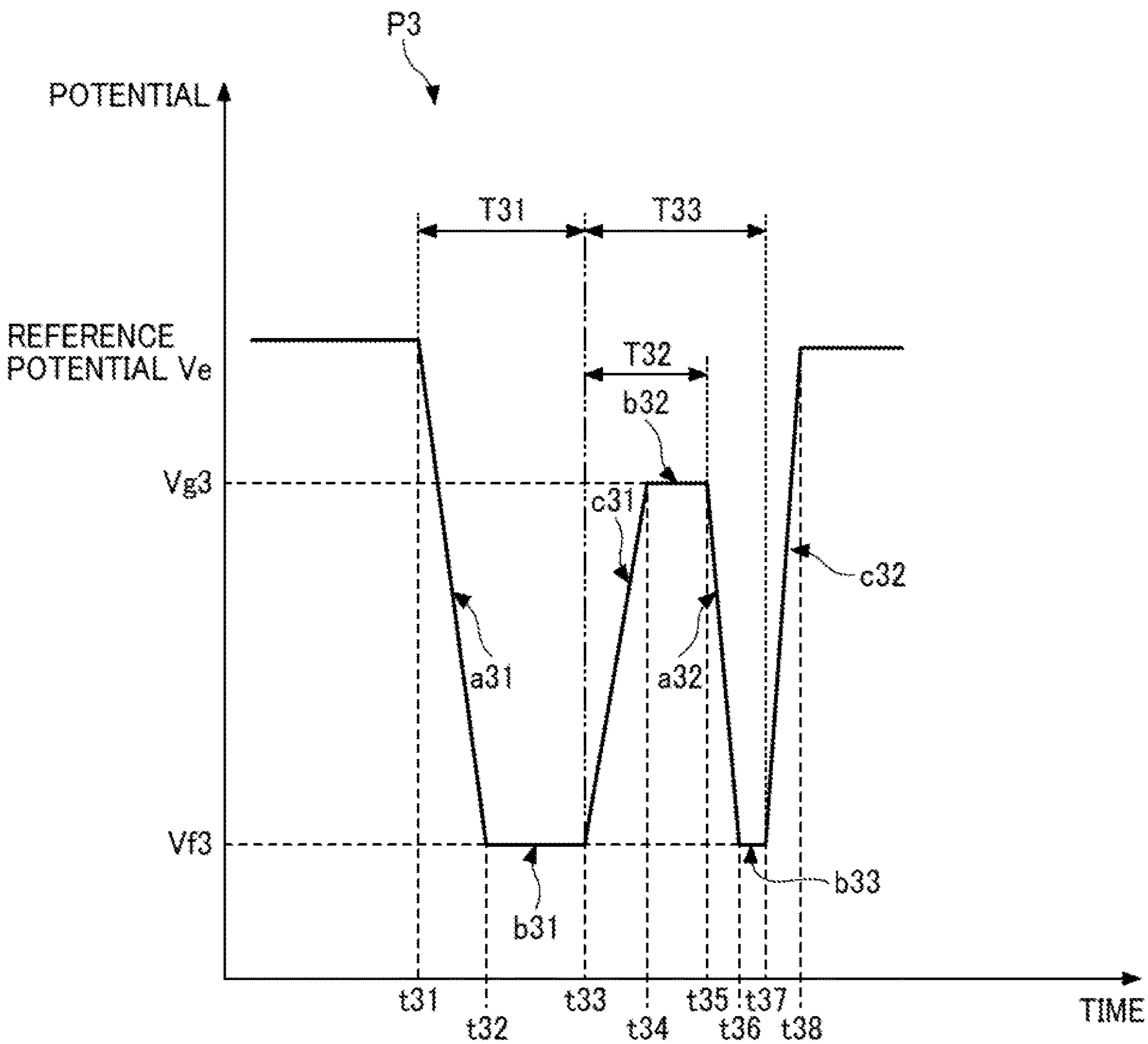

P3
POTENTIAL
T31
T33
REFERENCE
POTENTIAL Ve
T32
b32
Vg3
c31
c32
a31
a32
Vf3
b33
b31
t31
t32
t33
t34
t35
t36
t37
t38
TIME

FIG. 15

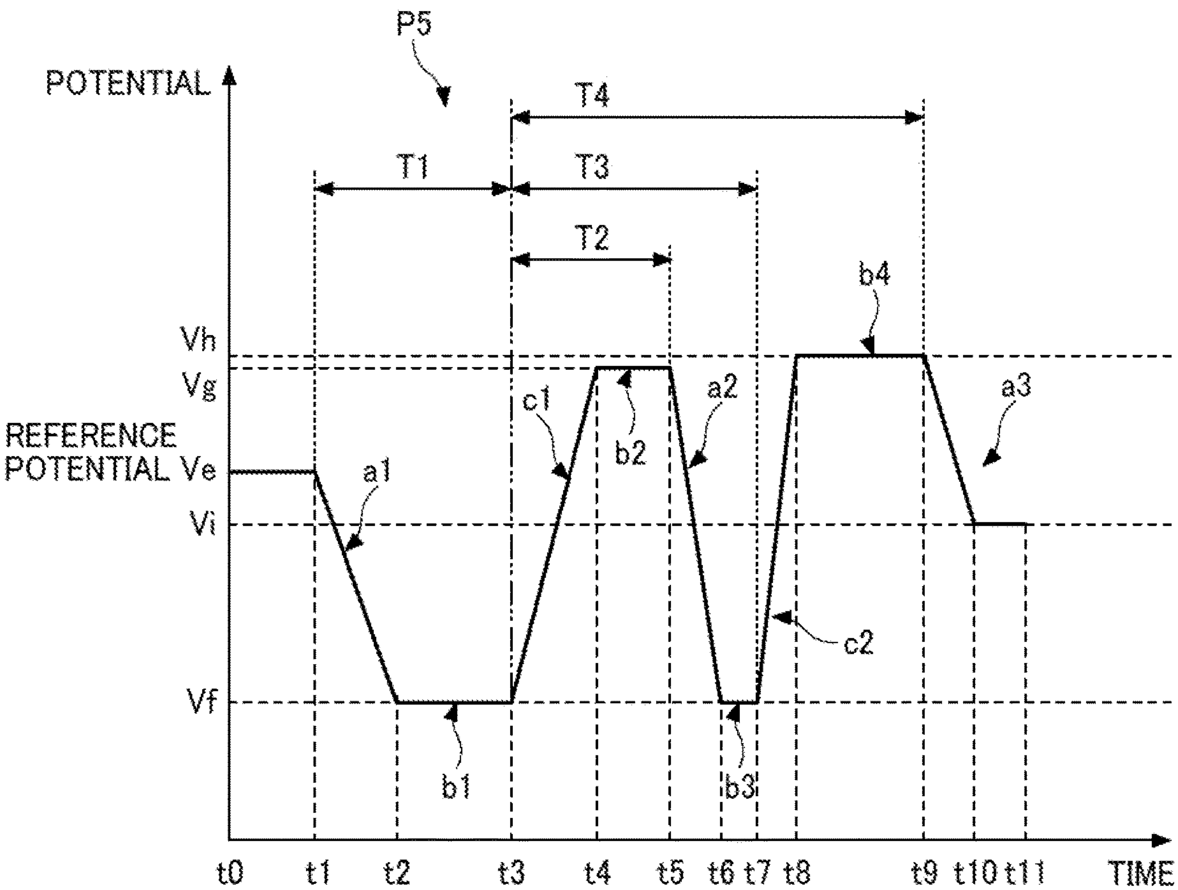

P5
POTENTIAL
T4
T1
T3
T2
b4
Vh
Vg
c1
b2
a2
a3
REFERENCE
POTENTIAL Ve
a1
Vi
c2
Vf
b1
b3
t0
t1
t2
t3
t4
t5
t6
t7
t8
t9
t10
t11
TIME

FIG. 16

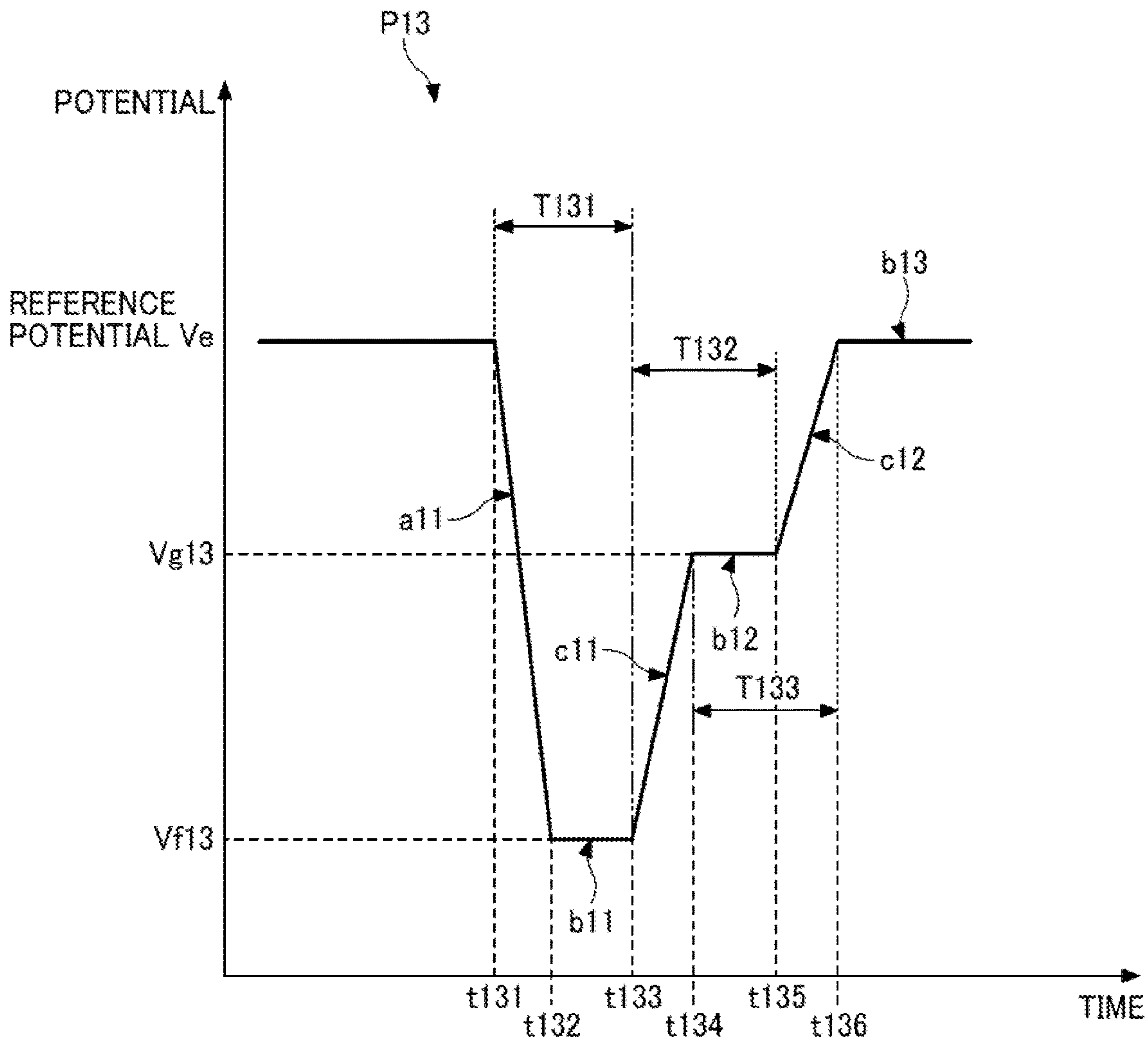
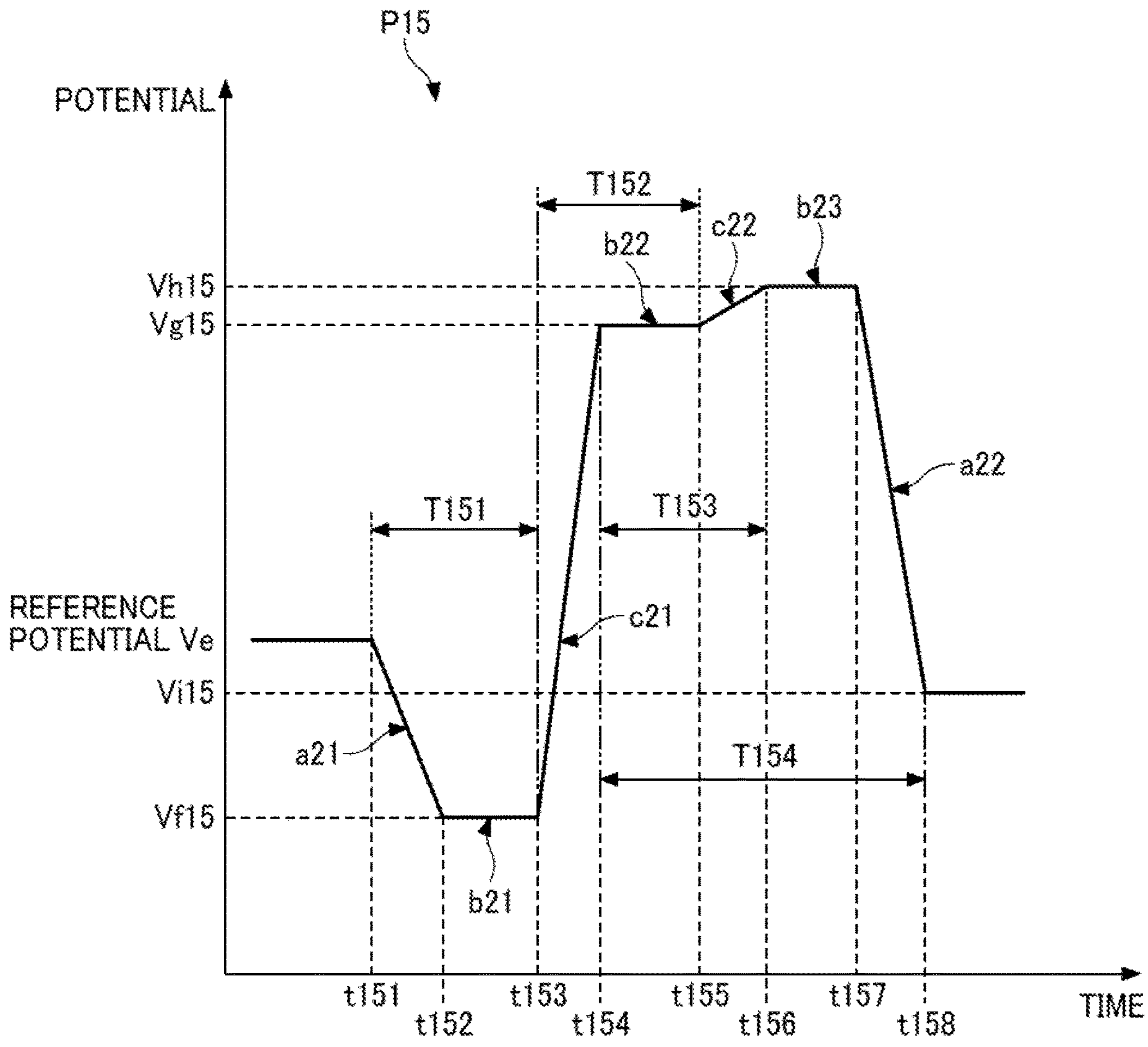

P13
POTENTIAL
T131
b13
REFERENCE
POTENTIAL Ve
T132
c12
a11
Vg13
b12
c11
T133
Vf13
b11
t131
t132
t133
t134
t135
t136
TIME

FIG. 17



P15
POTENTIAL
T152
b23
c22
b22
Vh15
Vg15
a22
T151
T153
REFERENCE
POTENTIAL Ve
c21
Vi15
T154
a21
Vf15
b21
t151
t152
t153
t154
t155
t156
t157
t158
TIME

FIG. 18

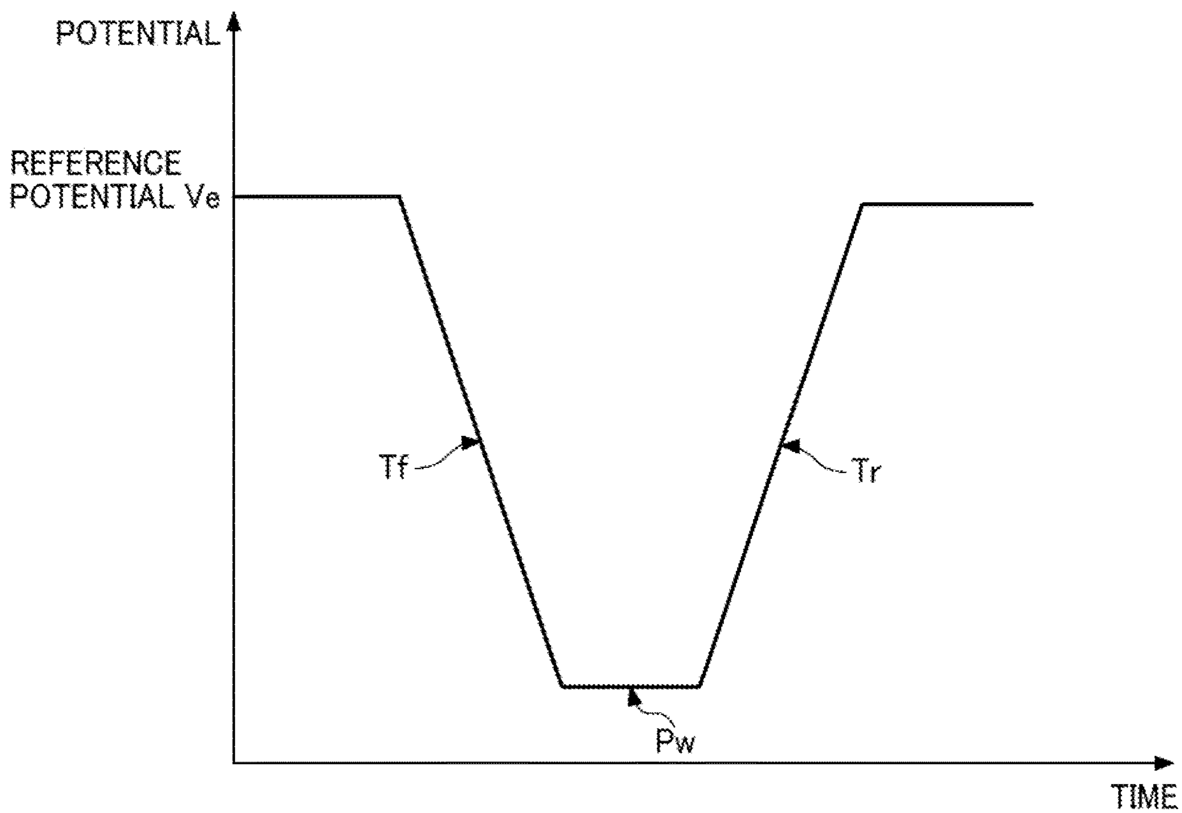
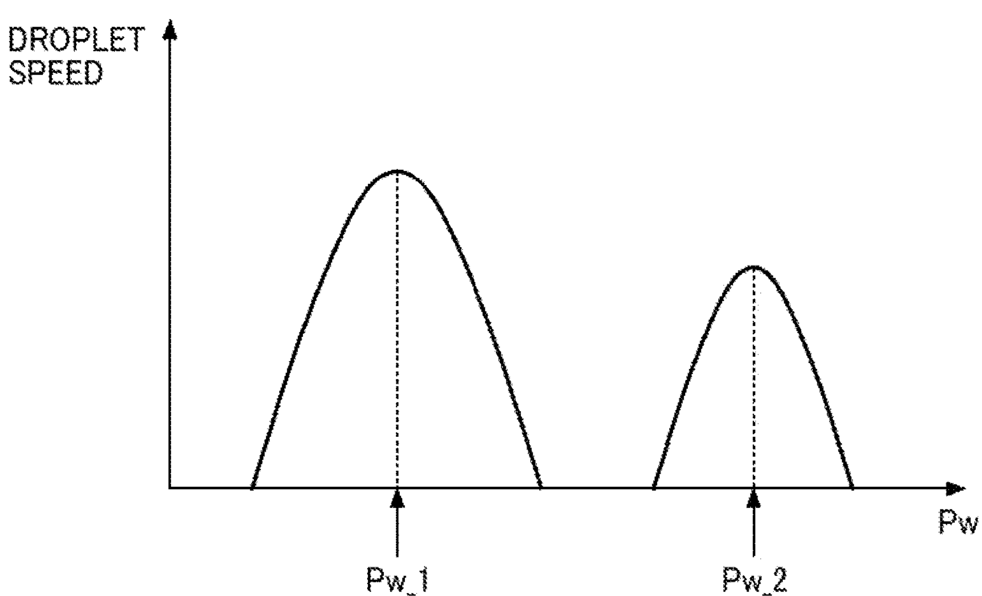

POTENTIAL
REFERENCE POTENTIAL Ve
Tf
Tr
Pw
TIME

FIG. 19


DROPLET SPEED
Pw
Pw_1
Pw_2

LIQUID DISCHARGE APPARATUS, NON-TRANSITORY COMPUTER-EXECUTABLE MEDIUM, AND METHOD FOR CONTROLLING DRIVING OF LIQUID DISCHARGE HEAD

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is based on and claims priority pursuant to 35 U.S.C. § 119(a) to Japanese Patent Application Nos. 2022-169272, filed on Oct. 21, 2022, and 2023-135962 filed on Aug. 24, 2023, in the Japan Patent Office, the entire disclosure of which is hereby incorporated by reference herein.

BACKGROUND

Technical Field

Embodiments of the present disclosure relate to a liquid discharge apparatus, a carrier means, and a method for controlling the driving of a liquid discharge head.

Related Art

Liquid discharge apparatuses including a liquid discharge head that discharges a liquid droplet are known. Some of such liquid discharge apparatuses output a drive waveform including one or two or more pulses selected according to a droplet size to a pressure generator.

SUMMARY

An embodiment of the present disclosure includes a liquid discharge apparatus. The liquid discharge apparatus includes a liquid discharge head including a plurality of nozzles to discharge liquid droplets, a plurality of individual liquid chambers communicating with the plurality of nozzles, and a plurality of pressure generators to generate a pressure that pressurizes liquid in the plurality of individual liquid chambers. The liquid discharge apparatus includes a head drive controller to output, to the plurality of pressure generators, a drive waveform including one pulse or two or more pulses selected according to a droplet size. In a case that the drive waveform includes the two or more pulses, the drive waveform includes a final pulse at an end of the two or more pulses. The final pulse includes a first expansion waveform element for expanding the plurality of individual liquid chambers, a first contraction waveform element for contracting the plurality of individual liquid chambers, the first contraction waveform element being subsequent to the first expansion waveform element, a second expansion waveform element for expanding the plurality of individual liquid chambers, the second expansion waveform element being subsequent to the first contraction waveform element, a second contraction waveform element for contracting the plurality of individual liquid chambers, the second contraction waveform element being subsequent to the second expansion waveform element, and a third expansion waveform element for expanding the plurality of individual liquid chambers, the third expansion waveform element being subsequent to the second contraction waveform element. When a natural vibration period of the plurality of the plurality of individual liquid chambers is defined as Tc, a time period from a start of the first contraction waveform element to a start of the second expansion waveform element is less than 0.5 Tc. A time period from the start of the first contraction waveform element to a start of the second contraction waveform element is within a range from 0.5 Tc to 0.6 Tc.

An embodiment of the present disclosure includes a non-transitory computer-executable medium storing a program storing instructions which, when executed by a processor of a computer, causes the computer to execute processing of discharging liquid from a plurality of nozzles of a liquid discharge head. The processing includes outputting, to a pressure generator, a drive waveform including one pulse or two or more pulses selected according to a droplet size. In a case that the drive waveform includes the two or more pulses, the drive waveform includes a final pulse at an end of the two or more pulses. The final pulse includes a first expansion waveform element for expanding a plurality of individual liquid chambers of the liquid discharge head, a first contraction waveform element for contracting the plurality of individual liquid chambers, the first contraction waveform element being subsequent to the first expansion waveform element, a second expansion waveform element for expanding the plurality of individual liquid chambers, the second expansion waveform element being subsequent to the first contraction waveform element, a second contraction waveform element for contracting the plurality of individual liquid chambers, the second contraction waveform element being subsequent to the second expansion waveform element, and a third expansion waveform element for expanding the plurality of individual liquid chambers, the third expansion waveform element being subsequent to the second contraction waveform element. When a natural vibration period of the plurality of the plurality of individual liquid chambers is defined as Tc, a time period from a start of the first contraction waveform element to a start of the second expansion waveform element is less than 0.5 Tc. A time period from the start of the first contraction waveform element to a start of the second contraction waveform element is within a range from 0.5 Tc to 0.6 Tc.

An embodiment of the present disclosure includes a method for controlling a driving of a liquid discharge head including a plurality of nozzles to discharge liquid droplets, a plurality of individual liquid chambers communicating with the plurality of nozzles, and a plurality of pressure generators to generate a pressure that pressurizes liquid in the individual liquid chambers. The method includes outputting, to the plurality of pressure generators, a drive waveform including one pulse or two or more pulses selected according to a droplet size. In a case that the drive waveform includes the two or more pulses, the drive waveform includes a final pulse at an end of the two or more pulses. The final pulse includes a first expansion waveform element for expanding the plurality of individual liquid chambers, a first contraction waveform element for contracting the plurality of individual liquid chambers, the first contraction waveform element being subsequent to the first expansion waveform element, a second expansion waveform element for expanding the plurality of individual liquid chambers, the second expansion waveform element being subsequent to the first contraction waveform element, a second contraction waveform element for contracting the plurality of individual liquid chambers, the second contraction waveform element being subsequent to the second expansion waveform element, and a third expansion waveform element for expanding the plurality of individual liquid chambers, the third expansion waveform element being subsequent to the second contraction waveform element. When a natural vibration period of the plurality of the

plurality of individual liquid chambers is defined as Tc, a time period from a start of the first contraction waveform element to a start of the second expansion waveform element is less than 0.5 Tc. A time period from the start of the first contraction waveform element to a start of the second contraction waveform element is within a range from 0.5 Tc to 0.6 Tc.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of embodiments of the present 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:

FIG. **1** is a schematic side view of an image forming apparatus, according to an embodiment of the present disclosure;

FIG. **2** is a plan view of the image forming apparatus, according to an embodiment of the present disclosure;

FIG. **3** is a cross-sectional view of a recording head, according to an embodiment of the present disclosure;

FIG. **4** is a cross-sectional view of the recording head, according to an embodiment of the present disclosure;

FIG. **5** is a block diagram illustrating a controller of the image forming apparatus, according to an embodiment of the present disclosure;

FIG. **6** is a block diagram illustrating a print controller and a head driver, according to an embodiment of the present disclosure;

FIG. **7** is a waveform chart illustrating a drive waveform, according to Embodiment 1;

FIG. **8** is a waveform chart illustrating a drive waveform including multiple pulses, droplet control signals, and pulses corresponding to droplet sizes, according to an embodiment of the present disclosure;

FIG. **9** is a waveform chart illustrating a pulse P**5** in the drive waveform, according to Embodiment 1 of the present disclosure;

FIG. **10**A to FIG. **10**D are diagrams illustrating how a droplet is discharged from a nozzle, according to an embodiment of the present disclosure;

FIG. **11** is a waveform chart illustrating a drive waveform, according to Comparative Example 1 of the present disclosure;

FIG. **12** is a graph illustrating a satellite length when a droplet is discharged using the drive waveforms according to Example 1, Example 2, and Comparative Example 1 of the present disclosure;

FIG. **13** is a graph illustrating the change amount of a sub-scanning speed fluctuation rate, according to an embodiment of the present disclosure;

FIG. **14** is a waveform chart illustrating a pulse P**3** in the drive waveform, according to Embodiment 1 of the present disclosure;

FIG. **15** is a waveform chart illustrating the pulse P**5** in the drive waveform, according to Embodiment 2 of the present disclosure;

FIG. **16** is a waveform chart illustrating the pulse P**13** in the drive waveform, according to Comparative Example 1 of the present disclosure;

FIG. **17** is a waveform chart illustrating the pulse P**15** in the drive waveform, according to Comparative Example 1 of the present disclosure;

FIG. **18** is a waveform chart illustrating the waveform shape of a driving pulse, and is a waveform chart illustrating a single pulse formed by a single waveform, according to an embodiment of the present disclosure; and

FIG. **19** is a graph illustrating the relation between a pulse width Pw and a droplet speed, according to an embodiment of the present disclosure.

The accompanying drawings are intended to depict embodiments of the present disclosure 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. Also, identical or similar reference numerals designate identical or similar components throughout the several views.

DETAILED DESCRIPTION

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.

Referring now to the drawings, embodiments of the present disclosure are described below. 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.

A liquid discharge apparatus, a program, and a head drive control method according to embodiments of the present disclosure are described below with reference to the drawings. In the present specification, an image forming apparatus that forms an image on a medium with liquid is a liquid discharge apparatus according to an embodiment of the present disclosure.

Overview of Image Forming Apparatus

FIG. **1** is a schematic side view of an image forming apparatus according to an embodiment of the present disclosure. FIG. **2** is a plan view of the image forming apparatus according to an embodiment of the present disclosure. The image forming apparatus **1** illustrated in FIG. **1** and FIG. **2** is a serial type inkjet recording apparatus. The image forming apparatus **1** includes a carriage **33** on which a recording head **34***a* and a recording head **34***b* are mounted. The carriage **33** is slidably supported by a pair of a guide rod **31** and a guide rod **32** extending in the main-scanning direction, and moves in the main-scanning direction. The carriage **33** can scan in the main-scanning direction. The pair of the guide rod **31** and the guide rod **32** is supported by a left side plate **21**A and a right side plate **21**B of the apparatus body. A main scanning motor transmits driving force via a timing belt to move the carriage **33**.

Recording Head

The recording head **34***a* and the recording head **34***b* are each a liquid discharge head according to an embodiment of the present disclosure. In the following description, the recording head **34***a* and the recording head **34***b* are referred to as a "recording head **34**" in a singular form or collectively referred to as "recording heads **34**," unless they need to be distinguished from each other. The recording head **34** discharges liquid droplets of colors of yellow (Y), cyan (C), magenta (M), and black (K). The liquid droplets may be ink droplets. The recording head **34** includes a nozzle plate on which multiple nozzles are formed from which liquid droplets are discharged. Multiple nozzle arrays are formed on the nozzle plate. The nozzle array includes multiple nozzles arranged in the sub-scanning direction. The sub-scanning direction intersects the main-scanning direction. The recording head **34** discharges liquid droplets downward, for example.

Each of the recording heads **34** has two nozzle arrays. The recording head **34***a* has a nozzle array from which black (K) liquid droplets are discharged and a nozzle array from which cyan (C) liquid droplets are discharged. The recording head **34***b* has a nozzle array from which magenta (M) liquid droplets are discharged and a nozzle array from which yellow (Y) liquid droplets are discharged. Alternatively, the recording head **34** may have one nozzle array, or may have three or more nozzle arrays.

Head Tank

A head tank **35***a* and a head tank **35***b* are mounted on the carriage **33**. The head tank **35***a* and the head tank **35***b* store inks corresponding to the multiple colors. The head tank **35***a* and the head tank **35***b* supply inks of the multiple colors to the recording heads **34**.

Ink Cartridge

To the image forming apparatus **1**, an ink cartridge **10***y*, an ink cartridge **10***m*, an ink cartridge **10***c*, and an ink cartridge **10***k* of the multiple colors are removably mounted. In the following description, the ink cartridge **10***y*, the ink cartridge **10***m*, the ink cartridge **10***c*, and the ink cartridge **10***k* are referred to as an "ink cartridge **10**" in a singular form or collectively referred to as "ink cartridges **10**," unless they need to be distinguished from each other. The ink cartridge **10** communicates with the head tank **35***a* and the head tank **35***b* through a supply tube **36**. The ink cartridge **10** supplies inks of the multiple colors to the head tank **35***a* and the head tank **35***b*.

Sheet Feeder

The image forming apparatus **1** includes a sheet feeder. The sheet feeder feeds a sheet **42** to the recording head **34**. The sheet **42** is a medium according to an embodiment of the present disclosure. The sheet feeder includes a sheet tray **2** that accommodates multiple sheets **42**. The sheets **42** are stacked on a sheet stacker **41** of the sheet tray **2**. The sheet feeder a semi-circular roller (sheet feeding roller) **43** and a separation pad **44**. The semi-circular roller **43** and the separation pad **44** are disposed to face each other. The semi-circular roller **43** and the separation pad **44** separate and feed the sheets **42** on the sheet stacker **41** one by one.

The sheet feeder includes a guide **45**, a counter roller **46**, a conveyance guide **47**, and a pressing member **48** having a leading end pressing roller **49**. The sheet feeder feeds the sheet **42** below the recording head **34**.

Conveyor

The image forming apparatus **1** includes a conveyor. The conveyor includes a conveyor belt **51**. The conveyor belt **51** electrostatically attracts the sheet **42** and conveys the sheet **42** to a position facing the recording head **34**. The conveyor belt **51** conveys the sheet **42** while attracting the sheet **42** with an electrostatic attraction force. The conveyor belt **51** is an endless belt, and is stretched between a conveyor roller **52** and a tension roller **53**. The conveyor belt **51** conveys the sheet **42** in the sub-scanning direction. The conveyor belt **51** is driven by the conveyor roller **52**.

The conveyor includes a charging roller **56** that charges the surface of the conveyor belt **51**. The charging roller **56** contacts a surface layer of the conveyor belt **51** and rotates according to the rotation of the conveyor belt **51**.

Sheet Ejector

The image forming apparatus **1** includes a sheet ejector. The sheet ejector ejects the sheet **42** on which an image is formed by droplets discharged from the recording head **34**. The sheet ejector includes a separation claw **61**, a sheet ejection roller **62**, and a spur roller **63** serving as a sheet ejection roller. The sheet ejector separates the sheet **42** from the conveyor belt **51**. The sheet ejector includes an output tray **3**. The output tray **3** receives the sheet **42** separated from the conveyor belt **51**.

Duplex Unit

The image forming apparatus **1** includes a duplex unit **71**. The duplex unit **71** is removably attached to the rear portion of the apparatus body of the image forming apparatus **1**. The duplex unit **71** draws and reverses the sheet **42** sent back by reverse rotation of the conveyor belt **51**. The duplex unit **71** feeds the sheet **42** toward a position between the counter roller **46** and the conveyor belt **51** again. An upper surface of the duplex unit **71** is used as a manual sheet feeding tray **72**.

Maintenance Unit

The image forming apparatus **1** includes a maintenance unit **81**. The maintenance unit **81** is disposed in a non-print area on one end in the main-scanning direction. The maintenance unit **81** performs maintenance operation for maintaining or recovering the state of the nozzles of the recording head **34**. The maintenance unit **81** includes a cap **82***a* and a cap **82***b* to cap the surface of the nozzle plate of the recording head **34**. The surface of the nozzle plate is the bottom face of the nozzle plate and is a face on which the nozzles are formed.

The maintenance unit **81** includes a wiper **83** and a dummy discharge receptacle **88**. The wiper **83** wipes the surface of the nozzle plate. The dummy discharge receptacle **88** receives liquid droplets discharged from the recording head **34**. The recording head **34** can perform dummy discharge for discharging thickened liquid. The liquid droplets discharged by performing the dummy discharge do not contribute to image formation and are received by the dummy discharge receptacle **88**.

The maintenance unit **81** includes a carriage lock **87** to lock the carriage **33**. The image forming apparatus **1** includes a waste liquid tank **100** to accommodate waste liquid generated by the maintenance operation. The waste liquid tank **100** is disposed on a lower side of the maintenance unit **81**. The waste liquid tank **100** is removably attached to the apparatus body.

The image forming apparatus **1** includes the dummy discharge receptacle **88** disposed in a non-print area on the other end in the main-scanning direction. The dummy discharge receptacle **88** receives liquid droplets discharged from the recording head **34** when the dummy discharge is performed.

An opening **89** is formed in the dummy discharge receptacle **88**. The opening **89** extends in the direction in which the nozzle array of the recording head **34** are arranged.

Operation by Image Forming Apparatus **1**

In the image forming apparatus **1**, the sheet **42** is fed from the sheet tray **2**. The sheet **42** is guided by the guide **45** and conveyed while being nipped between the conveyor belt **51** and the counter roller **46**. The leading end of the sheet **42** is guided by the conveyance guide **47** and pressed against the conveyor belt **51** by the leading end pressing roller **49**. Thus, the conveyance direction of the sheet **42** is turned substantially 90°.

At this time, the conveyor belt **51** is charged in an alternating charge voltage pattern by the charging roller **56**. When the sheet **42** is fed onto the charged conveyor belt **51**, the sheet **42** is attracted by the conveyor belt **51**, and the sheet **42** is conveyed in the sub-scanning direction by circular movement of the conveyor belt **51**.

The image forming apparatus **1** drives the recording head **34** according to image signals while moving the carriage **33**. The recording head **34** discharges liquid droplets onto the stopped sheet **42** to record one line and conveys the sheet **42** by a predetermined amount to record next line. In response to receiving a recording end signal or a signal indicating that a trailing edge of the sheet **42** has reached the recording area, the image forming apparatus **1** ends the recording operation and ejects the sheet **42** on the output tray **3**.

Recording Head

The recording head **34** is described below with reference to FIG. **3** and FIG. **4**. FIG. **3** and FIG. **4** are cross-sectional views of the recording head **34**. FIG. **3** and FIG. **4** are cross-sectional views of the recording head **34** along the longitudinal direction of an individual liquid chamber. The longitudinal direction of the individual liquid chamber is a direction orthogonal to the direction in which the nozzles are arrayed.

The recording head **34** includes a channel plate **101**, a diaphragm **102**, and a nozzle plate **103**. The channel plate **101** is layered on the nozzle plate **103**. The diaphragm **102** is layered on the channel plate **101**.

The nozzle plate **103** includes multiple nozzles **104** from which liquid droplets are discharged. The channel plate **101** includes through holes **105**, individual liquid chambers **106**, fluid restrictors **107**, and liquid introduction portions **108**. The through holes **105** communicate with the nozzles **104**. The through holes **105**, the individual liquid chambers **106**, the fluid restrictors **107**, and the liquid introduction portions **108** communicate with each other.

The recording head **34** includes a frame **117**. The frame **117** includes a common liquid chamber **110**. The diaphragm **102** includes a filter portion **109**. The filter portion **109** is located between the common liquid chamber **110** and the liquid introduction portions **108**. Ink is supplied to the liquid introduction portions **108** from the common liquid chamber **110**.

The ink in the liquid introduction portions **108** flows through the fluid restrictors **107** and is supplied to the individual liquid chambers **106**. The ink in the individual liquid chambers **106** flows through the through holes **105** and is discharged from the nozzles **104**. The "individual liquid chamber" is sometimes referred to as, for example, a pressuring chamber, a pressurized liquid chamber, a pressure chamber, an individual pressure channel, or a pressure generation chamber.

The channel plate **101** is formed by laminating metal plates made of, for example, stainless steel (SUS). Ports and grooves are formed in the channel plate **101**. The through holes **105**, the individual liquid chambers **106**, the fluid restrictors **107**, and the liquid introduction portions **108** are formed by the ports and the grooves.

The diaphragm **102** forms wall surfaces of the individual liquid chambers **106**, the fluid restrictors **107**, and the liquid introduction portions **108**. Further, the diaphragm **102** forms the filter portion **109**. The description given above is of a case in which the channel plate **101** is formed by laminating metal plates made of, for example, SUS. Alternatively, the channel plate **101** is formed by anisotropically etching a silicon substrate.

The recording head **34** includes piezoelectric members **112**. Each piezoelectric member **112** is disposed on a surface of the diaphragm **102** opposite to the individual liquid chambers **106**. The piezoelectric member **112** is an actuator (pressure generator) that generates energy to discharge a droplet. The piezoelectric member **112** is formed in a pillar shape by stacking multiple piezoelectric elements. A flexible printed circuit (FPC) **115** that transmits a drive waveform is connected to the piezoelectric member **112**.

The piezoelectric member **112** is used in the d**33** mode in which the piezoelectric member **112** expands and contracts in the stacking direction. The piezoelectric member **112** is not limited to one used in the d**33** mode. Alternatively, the piezoelectric member **112** is used in the d**31** mode that expands and contracts in a direction orthogonal to the stacking direction.

The recording head **34** contracts the piezoelectric member **112** by lowering the voltage applied to the piezoelectric member **112** from the reference potential Ve. The contraction of the piezoelectric member **112** deforms the diaphragm **102**, and thus the volume of the individual liquid chambers **106** expands. As a result, ink flows from the fluid restrictor **107** into the individual liquid chambers **106**.

The recording head **34** expands the piezoelectric member **112** after contracting the piezoelectric member **112**.

As illustrated in FIG. **4**, the recording head **34** expands the piezoelectric member **112** in the stacking direction by increasing the voltage applied to the piezoelectric member **112**. The expansion of the piezoelectric member **112** in the stacking direction deforms the diaphragm **102** to the side opposite to the piezoelectric member **112**, and thus the volume of the individual liquid chamber **106** reduces. As a result, ink in the individual liquid chambers **106** is pressurized, and droplets are discharged from the nozzles **104**.

The recording head **34** changes the diaphragm **102** to the initial position by changing the voltage applied to the piezoelectric member **112** back to the reference potential Ve. At this time, the individual liquid chambers **106** expand. As a result, ink is filled from the common liquid chamber **110** into the individual liquid chambers **106**. After the vibration of a meniscus surface of each nozzle **104** is attenuated and stabilized, an operation for the next droplet discharge is started.

Natural Vibration Period Tc

A natural vibration period Tc of each individual liquid chamber **106** of the recording head **34** is described below. As described above, by changing the volumes of the individual liquid chambers **106**, the recording head **34** pressurizes ink in the individual liquid chambers **106** and thus discharges liquid droplets from the nozzles **104**. At this time, when the ink in the individual liquid chamber **106** is pressurized, pressure vibration is generated according to a natural frequency of the individual liquid chambers **106**. The period of the pressure vibration is referred to as the natural vibration period Tc of the individual liquid chamber **106**. Typically, the natural vibration period Tc of the individual liquid chamber **106** corresponds to the natural vibration period of the pressure of ink determined by, for example, the physical properties of the ink, the shapes of the individual liquid chamber **106** or the nozzle **104**, or the materials of the individual liquid chamber **106** or the flow path. Such a natural vibration period Tc of the individual liquid chamber **106** is called the Helmholtz period.

Image Forming Apparatus 1

An overview of a controller **500** of the image forming apparatus **1** is described below with reference to FIG. **5**. FIG. **5** is a block diagram illustrating the controller **500** according to an embodiment of the present disclosure. The image forming apparatus **1** includes a controller **500** (control device).

The controller **500** includes a central processing unit (CPU) **501**, a read only memory (ROM) **502**, and a random access memory (RAM) **503**. The CPU **501** controls overall operation of the image forming apparatus **1**. The ROM **502** stores fixed data, such as various programs including programs executed by the CPU **501**. The RAM **503** temporarily stores image data and other data. The controller **500** further includes a nonvolatile random access memory (NVRAM) **504** and an application specific integrated circuit (ASIC) **505**. The NVRAM **504** is a rewritable memory that retains data even when the controller **500** is powered off. The ASIC **505** processes various signals on image data, performs sorting or other image processing, and processes input and output signals to control overall operation of the image forming apparatus **1**.

The controller **500** includes a print controller **508**. The print controller **508** includes a data transmitter and a driving signal generator that control the driving of the recording head **34**. The carriage **33** includes a head driver (driver IC) **509** that drives the recording head **34**. The head driver **509** is a head drive controller according to an embodiment of the present disclosure. The head driver **509** can execute a head drive control method. Alternatively, the controller **500** executes a part or all of the processes executed by the head driver **509**.

The controller **500** includes a motor driver **510**. The image forming apparatus **1** includes a main scanning motor **554**, a sub-scanning motor **555**, and a maintenance motor **556**. The main scanning motor **554** moves the carriage **33** for scanning. The sub-scanning motor **555** moves the conveyor belt **51** in the circumferential direction. The maintenance motor **556** outputs power used for, for example, driving the cap **82** of the maintenance unit **81**, moving the wiper **83**, and the suction by a suction pump. The motor driver **510** controls the driving of the main scanning motor **554**, the sub-scanning motor **555**, and the maintenance motor **556**.

The controller **500** includes an alternating-current (AC) bias supply **511** and a supply driver **512**. The AC bias supply **511** supplies an AC bias to the charging roller **56**. The supply driver **512** controls the driving of a liquid feed pump **241**. The image forming apparatus **1** includes the liquid feed pump **241**. The liquid feed pump **241** supplies ink in the ink cartridge **10** to the head tank **35***a* and the head tank **35***b*.

The controller **500** is coupled to a control panel **514** to input and display information to be used at the image forming apparatus **1**.

The controller **500** includes a host interface (I/F) **506**. The host I/F **506** is an interface for transmission and reception of data and signals to and from the host **600**. The host **600** includes an information processing apparatus such as a personal computer, an image reading apparatus, and an imaging device. The controller **500** is connected to the host **600** through a cable or a network.

The controller **500** receives data and signals from the host **600** through the host I/F **506**.

The CPU **501** of the controller **500** reads print data in a reception buffer included in the host I/F **506** and analyzes the print data. The ASIC **505** performs, for example, image processing and data-sorting processing on the analyzed print data. The controller **500** transfers the image data processed by the ASIC **505** from the print controller **508** to the head driver **509**. The host **600** includes a printer driver **601**. The printer driver **601** can generate dot pattern data for outputting an image. Alternatively or additionally, the controller **500** generates the dot pattern data.

The print controller **508** can transfer the image data as serial data.

The print controller **508** outputs, to the head driver **509**, a transfer clock, a latch signal, and a control signal to be used for, for example, transferring the image data and determining the transfer.

The controller **500** includes a driving signal generator. The driving signal generator a digital/analog (D/A) converter, a voltage amplifier, and a current amplifier. The driving signal generator performs digital-to-analog (D/A) conversion on the pattern data of the drive waveform stored in the ROM. The drive waveform includes one or more driving pulses. The print controller **508** outputs the drive waveform to the head driver **509**.

The head driver **509** selects a driving pulse from the one or driving pulses included in the drive waveform. The head driver **509** selects the driving pulse on the basis of serially-input image data corresponding to one line of the recording head **34**. The head driver **509** supplies the selected driving pulse to the piezoelectric member **112**. The head driver **509** drives the recording head **34** by supplying the driving pulse to the piezoelectric member **112**.

The head driver **509** selects a part or all of the driving pulses forming the drive waveform to selectively discharge dots of different sizes. The dots having different sizes include, for example, large droplets, medium droplets, and small droplets. The head driver **509** selectively discharges, the large droplets, the medium droplets, and the small droplets by selecting all or a part of the waveform elements forming the driving pulse.

The controller **500** includes an input/output (I/O) unit **513**. The image forming apparatus **1** includes various types of sensors **515**. The I/O unit **513** acquires data from the various types of sensors **515**. The I/O unit **513** extracts data to be used for controlling the printer from the acquired data. The print controller **508**, the motor driver **510**, and the AC bias supply **511** use the extracted data for various types of control.

The image forming apparatus **1** includes, as the various types of sensors **515**, for example, an optical sensor to detect the position of the sheet **42**, a thermistor to monitor temperature inside the image forming apparatus **1**, a sensor to monitor the voltage of a charging belt, and an interlock switch to detect opening and closing of a cover.

Print Controller and Head Driver

The print controller **508** and the head driver **509** according to one embodiment of the present disclosure is described below with reference to a block diagram of FIG. **6**. FIG. **6** is a block diagram illustrating the print controller **508** and the head driver **509**.

The print controller **508** includes a drive waveform generator **701** and a data transmitter **702**.

The drive waveform generator **701** generates a drive waveform (common drive waveform) including multiple pulses (driving signals) within one print period (one drive period) during image formation, and outputs the generated drive waveform. The data transmitter **702** outputs 2-bit image data (gradation signals **0** and **1**) corresponding to a print image, clock signals, latch signals (LAT), and droplet control signals M**0** to M**3**.

The droplet control signal is a 2-bit signal that instructs the opening and closing of an analog switch **715** for each droplet. The analog switch **715** is a switch of the head driver **509**. The droplet control signal transits the states to the level H (ON) for a pulse or a waveform element to be selected and to the level L (OFF) for a pulse or a waveform not to be selected in accordance with a printing period of the common drive waveform.

The print controller **508** selects a pulse for large droplets with the droplet control signal M**3**, a pulse for medium droplets with the droplet control signal M**2**, a pulse for small droplets with the droplet control signal M**2**, and a pulse for a micro drive with the droplet control signal M**0**.

The head driver **509** includes a shift register **711** and a latch circuit **712**. The shift register **711** inputs a transfer clock (shift clock) and serial image data (gradation data: 2 bits/1 channel (1 nozzle)) from the data transmitter **702**. The latch circuit **712** latches each register value of the shift register **711** by the latch signal.

The head driver **509** includes a decoder **713** and a level shifter **714**. The decoder **713** decodes the gradation data and the droplets control signals M**0** to M**3** to output the result of decoding. The level shifter **714** converts the level of a logic level voltage signal of the decoder **713**. The level shifter **714** converts the level of the logic level voltage signal of the decoder **713** to a level at which the analog switch **715** can operate. The analog switch **715** is turned on and off (opened and closed) according to the output from the decoder **713** provided through the level shifter **714**.

The analog switch **715** is coupled to a selection electrode (individual electrode) of each piezoelectric member **112**. The drive waveform generator **701** inputs the common drive waveform Pv to the analog switch **715**. The analog switch **715** is turned on according to image data (gradation data) by means of serial transfer and the result obtained by decoding the droplet control signals M**0** to M**3** by the decoder **713**. As the analog switch **715** is turned on, pulses (or waveform elements) contained in the common drive waveform Pv pass (are selected). The passed pulses are applied to the piezoelectric member **112**.

A drive waveform according to Embodiment 1 of the present disclosure is described below with reference to FIG. **7**. FIG. **7** is a waveform chart illustrating a drive waveform according to Embodiment 1 of the present disclosure. In FIG. **7**, the horizontal axis represents time, and the vertical axis represents potential.

The term "pulse" is used as a term indicating a driving pulse as an element contained in the drive waveform. The term "discharge pulse" is used as a term indicating a driving pulse applied to the pressure generator to discharge a liquid droplet. The term "non-discharge pulse" is used as a term indicating a driving pulse (micro driving pulse) applied to the pressure generator and drives the pressure generator to such an extent that a droplet is not discharged, e.g., to such an extent that ink in the nozzle is caused to flow. The drive waveforms and the pulses as elements of the drive waveforms described below are merely examples, and any other suitable drive waveform and pulse can be used.

The drive waveform (common drive waveform) Pv illustrated in FIG. **7** includes pulses P**1** to P**5** in one print cycle (one drive cycle). The pulse P**1** is a micro driving pulse. The pulses P**2** to P**5** are discharge pulses. The pulses P**1** to P**5** are generated in a chronological order.

FIG. **8** illustrates a drive waveform including multiple pulses, droplet control signals, and pulses corresponding to the droplet sizes. In FIG. **8**, the horizontal axis represents time. In FIG. **8**, the drive waveform Pv, the droplet control signals M**0** to M**3**, the waveform for large droplets, the waveform for medium droplets, the waveform for small droplets, and the drive waveform for micro drive are illustrated in order from the top.

The head driver **509** selects one or more pulses from the pulses P**1** to P**5** according to the droplet control signals M**0** to M**3** illustrated in FIG. **8**. The head driver **509** supplies the one or more pulses selected from the pulses P**1** to P**5** to the pressure generator. Depending on the drop size, the one or more pulses are selected. As a result of the selection, a discharge drive waveform for large droplets (the waveform for large droplets), a discharge drive waveform for medium droplets (the waveform for medium droplets), a discharge drive waveform for small droplets (the waveform for small droplets), and the waveform for micro drive are obtained.

The waveform for large droplets includes the pulses P**1** to P**5**. Due to the selection of the pulses P**1** to P**5**, the waveform for large droplets is obtained. By supplying the pulses P**2** to P**5** to the pressure generator, liquid droplets corresponding the supplied pulses are discharged. The droplets discharged due to the selection of the pulses P**2** to P**5** are combined during flight, and thus forms a large droplet.

The waveform for medium droplets includes the pulses P**2** and P**4**. Due to the selection of the pulses P**2** and P**4**, the waveform for medium droplets is obtained. By supplying the pulses P**2** and P**4** to the pressure generator, liquid droplets corresponding the supplied pulses are discharged. The droplets discharged due to the selection of the pulses P**2** and P**4** are combined during flight, and thus forms a medium droplet.

The waveform for small droplets includes the pulse P**3**. Due to the selection of the pulse P**3**, the waveform for small droplets is obtained. By supplying the pulse P**3** to the pressure generator, a liquid droplet (small droplet) is discharged.

The waveform for micro drive includes the pulse P**1**. Due to the selection of the pulse P**1**, the waveform for micro drive is obtained. By supplying the pulse P**1** to the pressure generator, the diaphragm **102** slightly vibrates.

Pulse P**5**

The pulse P**5**, which is the last pulse among the multiple pulses included in the waveform for large droplets, is described below in detail with reference to FIG. **9**. FIG. **9** is a waveform chart illustrating the pulse P**5**, which is the final pulse. In FIG. **9**, the horizontal axis represents time, and the vertical axis represents potential. Time t**0** to time t**11** elapses in an ascending order of the number.

The pulse P**5** includes a first expansion waveform element (first pulling waveform element) a**1**, a holding waveform element b**1**, a first contraction waveform element (first pushing waveform element) c**1**, a holding waveform element b**2**, a second expansion waveform element (second pulling waveform element) a**2**, a holding waveform element b**3**, a second contraction waveform element (second pushing waveform element) c**2**, a holding waveform element b**4**, and a third expansion waveform element (third pulling waveform element) a**3**.

The first expansion waveform element a**1** falls from the reference potential Ve to a potential Vf to expand the individual liquid chamber **106**. The potential Vf is a potential lower than the reference potential Ve. The first expansion waveform element a**1** is at the reference potential Ve at the time t**1** and falls to the potential Vf at the time t**2**.

The holding waveform element b**1** holds the potential Vf for a predetermined time. The holding waveform element b**1** holds the potential Vf from the time t**2** to the time t**3**.

The first contraction waveform element c**1** rises from the potential Vf to a potential Vg (Vg>Ve) to contract the individual liquid chamber **106**, and thus a liquid droplet is discharged. The first contraction waveform element c**1** is at the potential Vf at the time t**3** and rises to the potential Vg at the time t**4**.

The holding waveform element b**2** holds the potential Vg raised by the first contraction waveform element c**1** for a predetermined time. The holding waveform element b**2** holds the potential Vg from the time t**4** to the time t**5**.

The second expansion waveform element a**2** falls from the potential Vg to the potential Vf to expand the individual liquid chamber **106**, and thus a part of the liquid droplet discharged by the first contraction waveform element c**1** is torn off and returned into the nozzle **104**. The second expansion waveform element a**2** is at the potential Vg at the time t**5** and falls to the potential Vf at the time t**6**.

The holding waveform element b**3** holds the potential Vf for a predetermined time. The holding waveform element b**3** holds the potential Vf from the time t**6** to the time t**7**.

The second contraction waveform element c**2** rises from the potential Vf to a potential Vh (Vg<Vh) to contract the individual liquid chamber **106**, and thus a liquid droplet is discharged. The second contraction waveform element c**2** is at the potential Vf at the time t**7** and rises to the potential Vh at the time t**8**.

The holding waveform element b**4** holds the potential Vh raised by the second contraction waveform element c**2** for a predetermined time. The holding waveform element b**4** holds the potential Vh from the time t**8** to the time t**9**.

The third expansion waveform element a**3** falls from the potential Vh to a potential Vi to expand the individual liquid chamber **106**, and thus a part of the liquid droplet discharged by the second contraction waveform element c**2** is torn off and returned into the nozzle **104**. No liquid droplet is discharged by the third expansion waveform element a**3**.

The first contraction waveform element c**1** is a waveform element that contracts the individual liquid chamber **106** at a time that resonates with the pressure fluctuation in the individual liquid chamber **106** caused by the first expansion waveform element a**1**.

The second contraction waveform element c**2** is a damping waveform element that damps the pressure fluctuation in the individual liquid chamber **106** caused by the first expansion waveform element a**1**, the first contraction waveform element c**1**, and the second expansion waveform element a**2**.

The third expansion waveform element a**3** is a damping waveform element that damps the pressure fluctuation in the individual liquid chamber **106** that cannot be damped by the second contraction waveform element c**2**.

Measurement Method of Natural Vibration Period Tc

A method of measuring the natural vibration cycle Tc is described below for describing the relation between the start and end of each of the waveform elements of the pulse P**5** illustrated in FIG. **9** and the natural vibration period Tc.

FIG. **18** is a waveform chart illustrating the waveform shape of a driving pulse, and is a waveform chart illustrating a single pulse formed by a single waveform. The driving pulse includes a waveform element Tf in which a potential falls from the reference potential Ve. The waveform element Tf that falls may be a fall time. As the waveform element Tf in which the potential falls from the reference potential Ve is supplied to the piezoelectric member **112**, the piezoelectric member **112** contracts and thus the volume of the individual liquid chamber **106** expands.

The driving pulse includes a pulse width Pw. The pulse width Pw is a waveform element subsequent to the waveform element Tf. The pulse width Pw is a waveform element for maintaining the state of the piezoelectric member **112** as a holding state. As the waveform element by the pulse width Pw is supplied to the piezoelectric member **112**, the state of the piezoelectric member **112** is maintained. This is called a holding state.

The driving pulse includes a waveform element Tr that rises from a potential at which the piezoelectric member **112** is in the holding state by the pulse width Pw. The waveform element Tr that rises may be a rise time. As the waveform element Tr that rises is supplied to the piezoelectric member **112**, the piezoelectric member **112** expands and the individual liquid chamber **106** contracts.

FIG. **19** is a graph illustrating the relation between the pulse width Pw and a droplet speed. The relation between the pulse width Pw and the droplet speed is referred to as a pulse width Pw characteristic. When the pulse width Pw supplied to the piezoelectric member **112** is changed, a meniscus vibrates at the resonance period of the Helmholtz natural vibration. The resonance period of the Helmholtz natural vibration is determined by, for example, the ink channel system formed by bonding several kinds of thin plates, the vibration system, the dimension of the piezoelectric element, the material system, and physical property values. When a time when the meniscus moves toward the outside of the nozzle coincides with a time when the meniscus is pushed out by the waveform element Tr serving as a rising element, the force for pushing out the meniscus becomes maximum and the droplet speed becomes the fastest.

As the pulse width Pw is increased, multiple peaks are generated. In FIG. **19**, the peak that appears first is illustrated as a first peak Pw**1**, and the peak that appears subsequently is illustrated as Pw**2**. The natural vibration period Tc of the pressure resonance is calculated from the difference between the first peak Pw**1** and the second peak Pw**2**.

The relation between the start and end of each of the waveform elements of the pulse P**5** illustrated in FIG. **9** and the natural vibration period Tc is described below.

A time period T**1** from the start of the first expansion waveform element a**1** to the start of the first contraction waveform element c**1** is 0.45 Tc to 0.65 Tc. This enhances the droplet discharge efficiency. The time period T**1** is from the time t**1** to the time t**3**.

A time period T**2** from the start of the first contraction waveform element c**1** to the start of the second expansion waveform element a**2** is less than 0.5 Tc. This shortens the satellite length. The time period T**2** is from the time t**3** to the time t**5**.

A time period T**3** from the start of the first contraction waveform element c**1** to the start of the second contraction waveform element c**2** is within the range from 0.5 Tc to 0.6 Tc. A time period T**4** from the start of the first contraction waveform element c**1** to the start of the third expansion waveform element a**3** is 0.9 Tc to 1.0 Tc. As a result, the second contraction waveform element c**2** and the third expansion waveform element a**3** serve as damping waveform elements that reduce or prevent the pressure fluctuations of the individual liquid chamber **106** caused by the first expansion waveform element a**1**, the first contraction waveform element c**1**, and the second expansion waveform element a**2**.

The time period T**1** to the time period T**4** are not limited to the above-described times. For example, the time period T**3** may be a time during which the individual liquid chamber **106** is contracted by the second contraction waveform element c**2** with a phase opposite to the pressure fluctuation of the individual liquid chamber **106**.

A droplet discharge is described below with reference to FIG. **10**A to FIG. **10**D. FIG. **10**A to FIG. **10**D are diagrams illustrating how a liquid droplet is discharged from the nozzle.

By applying the first expansion waveform element a**1** to the state illustrated in FIG. **10**A, a meniscus **300** is drawn into the nozzle **104** as illustrated in FIG. **10**B. By applying the first contraction waveform element c**1** after a predetermined time has elapsed, a portion that becomes a liquid droplet **301** protrudes as illustrated in FIG. **10**C. At this time, by applying the second expansion waveform element a**2**, a part of the liquid droplet **301** is torn off and returned to the inside of the nozzle **104**, as illustrated in FIG. **10**D.

Thus, the liquid droplet **301** becomes a small droplet, and the tail portion of the liquid droplet **301**, which becomes a satellite droplet or mist, is torn off and returned to the inside the nozzle **104**. As a result, the satellite droplet or mist is reduced.

Pulse P**3**

The pulse P**3** is described below with reference to FIG. **14**. FIG. **14** is a waveform chart illustrating the pulse P**3**. In FIG. **14**, the horizontal axis represents time, and the vertical axis represents potential. Time t**31** to time t**38** represented by the horizontal axis elapses in an ascending order of the number. As described above, the pulse P**3** is included in the waveform for large droplets and the waveform for small droplets.

The pulse P**3** includes a first expansion waveform element a**31**, a holding waveform element b**31**, a first contraction waveform element c**31**, a holding waveform element b**32**, a second expansion waveform element a**32**, a holding waveform element b**33**, and a second contraction waveform element c**32**.

The first expansion waveform element a**31** falls from the reference potential Ve to a potential Vf**3** to expand the individual liquid chamber **106**. The potential Vf**3** is a potential lower than the reference potential Ve. The first expansion waveform element a**31** is at the reference potential Ve at the time t**31** and falls to the potential Vf**3** at the time t**32**.

The holding waveform element b**31** holds the potential Vf**3** for a predetermined time. The holding waveform element b**31** holds the potential Vf**3** from the time t**32** to the time t**33**.

The first contraction waveform element c**31** rises from the potential Vf**3** to a potential Vg**3** (Vg**3**<Ve) to contract the individual liquid chamber **106**, and thus a liquid droplet is discharged. The first contraction waveform element c**31** is at the potential Vf**3** at the time t**33** and rises to the potential Vg**3** at the time t**34**.

The holding waveform element b**32** holds the potential Vg**3** raised by the first contraction waveform element c**31** for a predetermined time. The holding waveform element b**32** holds the potential Vg**3** from the time t**34** to the time t**35**.

The second expansion waveform element a**32** falls from the potential Vg**3** to the potential Vf**3** to expand the individual liquid chamber **106**, and thus a part of the liquid droplet discharged by the first contraction waveform element c**31** is torn off and returned into the nozzle **104**. The second expansion waveform element a**32** is at the potential Vg**3** at the time t**35** and falls to the potential Vf**3** at the time t**36**.

The holding waveform element b**33** holds the potential Vf**3** for a predetermined time. The holding waveform element b**33** holds the potential Vf**3** from the time t**36** to the time t**37**.

The second contraction waveform element c**32** rises from the potential Vf**3** to the potential Ve to contract the individual liquid chamber **106**, and thus a liquid droplet is discharged. The second contraction waveform element c**32** is at the potential Vf**3** at the time t**37** and rises to the reference potential Ve at the time t**38**.

A time period T**31** from the start of the first expansion waveform element a**31** to the start of the first contraction waveform element c**31** is within the range from 0.45 Tc to 0.65 Tc. This enhances the droplet discharge efficiency. The time period T**31** is from the time t**31** to the time t**33**.

A time period T**32** from the start of the first contraction waveform element c**31** to the start of the second expansion waveform element a**32** is less than 0.5 Tc. This shortens the satellite length. The time period T**32** is from the time t**33** to the time t**35**.

A time period T**33** from the start of the first contraction waveform element c**31** to the start of the second contraction waveform element c**32** is 0.5 Tc. As a result, the residual vibration generated by the first contraction waveform element c**31** is reduced or prevented by the second contraction waveform element c**32**. The time period T**33** is from the time t**33** to the time t**37**.

The time period T**31** to the time period T**33** are not limited to the above-described times. For example, the time period T**33** may be a time during which the individual liquid chamber **106** is contracted by the second contraction waveform element c**32** with a phase opposite to the pressure fluctuation of the individual liquid chamber **106**.

The image forming apparatus **1** (liquid discharge apparatus) according to the present embodiment generates the final pulse P**5** including the first expansion waveform element a**1** that expands the individual liquid chamber **106**, the first contraction waveform element c**1** that contracts the individual liquid chamber **106**, the second expansion waveform element a**2** that expands the individual liquid chamber **106**, the second contraction waveform element c**2** that contracts the individual liquid chamber **106**, and the third expansion waveform element a**3** that expands the individual liquid chamber **106**. In the image forming apparatus **1**, the head driver **509** (head drive controller) outputs a drive waveform including the final pulse P**5** at the end among the pulses P**1** to P**5** in a chronological order to the piezoelectric member **112** (pressure generator). Thus, the image forming apparatus **1** can reduce or prevent discharge deflection in discharge at a high frequency and reduce the generation of mist, and thus soil in the apparatus is reduced.

For example, the first contraction waveform element c**1** contracts the individual liquid chamber **106** at a time that resonates with the pressure fluctuation in the individual liquid chamber **106** caused by the first expansion waveform element a**1**, and the second contraction waveform element c**2** reduces or prevents the pressure fluctuation of the individual liquid chamber **106**. By discharging liquid droplets using the drive waveform including the final pulse P**5** including such waveform elements, the residual vibration in the individual liquid chamber **106** can be reduced or prevented.

Further, the time period T**2** from the start of the first contraction waveform element c**1** to the start of the second expansion waveform element a**2** is less than 0.5 Tc, and the time period T**3** from the start of the first contraction waveform element c**1** to the start of the second contraction waveform element c**2** is within the range from 0.5 Tc to 0.6 Tc. By discharging liquid droplets using the pulse P**5** including such waveform elements, the discharge deflection is reduced or prevented in discharge at a high frequency and the generation of mist is reduced, and thus the soil in the apparatus is reduced.

Further, the time period T**1** from the start of the first expansion waveform element a**1** to the start of the first contraction waveform element c**1** may be within the range from 0.45 Tc to 0.65 Tc. Further, the time period T**4** from the start of the first contraction waveform element c**1** to the start of the third expansion waveform element a**3** may be within the range from 0.9 Tc to 1.0 Tc.

Image Forming Apparatus According to Embodiment 2

A drive waveform in the image forming apparatus **1** according to Embodiment 2 is described below. The drive waveform in Embodiment 2 includes the pulses P**1**, P**2**, P**3**, P**4**, and P**5** in the same or substantially the same manner as the drive waveform in Embodiment 1 illustrated in FIG. **7** and FIG. **8**. The time period T**31** of the pulse P**3** of the drive waveform in Embodiment 2 has a different length from the time period T**31** of the pulse P**3** of the drive waveform in Embodiment 1. The time period T**1** and the time period T**4** of the pulse P**5** of the drive waveform in Embodiment 2 have different lengths from the time period T**1** and the time period T**4** of the pulse P**5** of the drive waveform in Embodiment 1. In the description of Embodiment 2, redundant descriptions similar to those of the Embodiment 1 are omitted below.

Pulse P**3**

As described above, the pulse P**3** of Embodiment 2 is different from the pulse P**3** of Embodiment 1 in the length of the time period T**31**. The pulse P**3** of Embodiment 2 is described with reference to FIG. **14**.

The time period T**31** from the start of the first expansion waveform element a**31** to the start of the first contraction waveform element c**31** is 0.3 Tc. The time period T**31** of the pulse P**3** of Embodiment 2 is shorter than the time period T**31** of the pulse P**3** of Embodiment 1.

In the pulse P**3** according to Embodiment 2, since the time period T**32** is less than 0.5 Tc and the time period T**33** is 0.5 Tc, the tail portion of a discharged droplet is torn off and returned to the inside of the nozzle **104**, and thus a satellite droplet or mist is reduced. The pulse P**3** according to Embodiment 2 produces the same or substantially the same effect as that of the pulse P**3** according to Embodiment 1. The pulse P**3** according to Embodiment 2 in which the time period T**31** is 0.3 Tc produces the same or substantially the same effect as that of the pulse P**3** according to Embodiment 1.

Pulse P**5**

The pulse P**5** of the drive waveform according to Embodiment 2 is described below with reference to FIG. **15**. FIG. **15** is a waveform chart illustrating the pulse P**5** in the drive waveform, according to Embodiment 2. As described above, the pulse P**5** of Embodiment 2 is different from the pulse P**5** of Embodiment 1 in the lengths of the time period T**1** and the time period T**4**.

The time period T**1** from the start of the first expansion waveform element a**1** to the start of the first contraction waveform element **c1** is 0.3 Tc. This enhances the droplet discharge efficiency. The time period T**1** from the start of the first expansion waveform element a**1** to the start of the first contraction waveform element **c1** is a range from the resonance time that enhances the droplet discharge efficiency, which is from the time t**1** to the time t**3**.

The time period T**4** from the start of the first contraction waveform element **c1** to the start of the third expansion waveform element a**3** is 1.25 Tc. As a result, the second contraction waveform element **c2** and the third expansion waveform element a**3** serve as damping waveform elements that reduce or prevent the pressure fluctuations of the individual liquid chamber **106** caused by the first expansion waveform element a**1**, the first contraction waveform element **c1**, and the second expansion waveform element a**2**. The time period T**4** is a time during which the second contraction waveform element **c2** and the third expansion waveform element a**3** serve as damping waveform elements that reduce or prevent the pressure fluctuations of the individual liquid chamber **106** caused by the first expansion waveform element a**1**, the first contraction waveform element **c1**, and the second expansion waveform element a**2**.

In the pulse P**5** according to Embodiment 2, since the time period T**2** is less than 0.5 Tc and the time period T**3** period is 0.5 Tc (within the range from 0.5 Tc to 0.6 Tc), the tail portion of a discharged droplet is torn off and returned to the inside of the nozzle **104**, and thus a satellite droplet or mist is reduced. The pulse P**5** according to Embodiment 2 produces the same or substantially the same effect as that of the pulse P**5** according to Embodiment 1.

Comparative Example 1

A drive waveform according to Comparative Example 1 is described below with reference to FIG. **11**, FIG. **16**, and FIG. **17**. FIG. **11** is a waveform chart illustrating a drive waveform according to Comparative Example 1. FIG. **11** illustrates a drive waveform Pv**11**, according to the comparative example. The drive waveform Pv**11** includes pulses P**1**, P**2**, P**13**, P**4**, and P**15**. The drive waveform Pv**11** differs from the drive waveform Pv illustrated in FIG. **8** in that the drive waveform Pv**11** includes a pulse P**13** instead of the pulse P**3** and a pulse P**15** instead of the pulse P**5**.

Pulse P**13** According to Comparative Example 1

FIG. **16** is a waveform chart illustrating the pulse P**13** in the drive waveform, according to Comparative Example 1. The pulse P**13** includes an expansion waveform element all, a holding waveform element b**11**, a contraction waveform element **c11**, a holding waveform element b**12**, a contraction waveform element **c12**, and a holding waveform element b**13**. As described below, the potential falls in the expansion waveform element a**11**. The potential is held in the holding waveform elements b**11**, b**12**, and b**13**.

The potential rises in the contraction waveform elements **c11** and **c12**.

The expansion waveform element all falls from the reference potential Ve to a potential Vf**13** to expand the individual liquid chamber **106**. The potential Vf**13** is a potential lower than the reference potential Ve. The expansion waveform element all is at the reference potential Ve at a time t**131** and falls to the potential Vf**13** at a time t**132**.

The holding waveform element b**11** holds the potential Vf**13** for a predetermined time. The holding waveform element b**11** holds the potential Vf**13** from the time t**132** to a time t**133**.

The contraction waveform element **c11** rises from the potential Vf**13** to a potential Vg**13** (Vg**13**<Ve) to contract the individual liquid chamber **106**, and thus a liquid droplet is discharged. The contraction waveform element **c11** is at the potential Vf**13** at the time t**133** and rises to the potential Vg**13** at a time t**134**.

The holding waveform element b**12** holds the potential Vg**13** raised by the contraction waveform element **c11** for a predetermined time. The holding waveform element b**12** holds the potential Vg**13** from the time t**134** to a time t**135**.

The contraction waveform element **c12** rises from the potential Vg**13** to the reference potential Ve to contract the individual liquid chamber **106**, and thus a liquid droplet is discharged. The contraction waveform element **c12** is at the potential Vg**13** at the time t**135** and rises to the reference potential Ve at a time t**136**.

A time period T**131** from the start of the expansion waveform element all to the start of the contraction waveform element **c11** in the pulse P**13** is 0.5 Tc. The time period T**131** is from the time t**131** to the time t**133**.

A time period T**132** from the start of the contraction waveform element **c11** to the start of the contraction waveform element c12 in the pulse P13 is 0.5 Tc. The time period T132 is from the time t133 to the time t135.

A time period T133 from the end of the contraction waveform element c11 to the end of the contraction waveform element c12 in the pulse P13 is 0.5 Tc. The time period T133 is from the time t134 to the time t136.

Such a pulse P13 can drive the piezoelectric member 112 of the individual liquid chamber 106 as a damping time that cancels the residual vibration that occurs after a liquid droplet is discharged by the contraction waveform element c11. With such a pulse P13, a liquid droplet discharged by the pulse P13 in the drive waveform of Comparative Example 1 is a small droplet. Thus, the residual vibration due to the contraction waveform element c11 can be reduced or prevented by the contraction waveform element c12.

However, with the pulse P13 according to Comparative Example 1, the tail of the discharged droplet cannot be torn off and then returned to the inside of the nozzle. Accordingly, a satellite droplet of mist cannot be sufficiently reduced.

Pulse P15 according to Comparative Example 1

FIG. 17 is a waveform chart illustrating the pulse P15 in the drive waveform, according to Comparative Example 1. The pulse P15 includes an expansion waveform element a21, a holding waveform element b21, a contraction waveform element c21, a holding waveform element b22, a contraction waveform element c22, a holding waveform element b23, and an expansion waveform element a22. As described below, the potential falls in the expansion waveform elements a21 and a22. The potential is held in the holding waveform elements b21, b22, and b23. The potential rises in the contraction waveform elements c21 and c22.

The expansion waveform element a21 falls from the reference potential Ve to a potential Vf15 to expand the individual liquid chamber 106. The potential Vf15 is a potential lower than the reference potential Ve. The expansion waveform element a21 is at the reference potential Ve at a time t151 and falls to the potential Vf15 at a time t152.

The holding waveform element b21 holds the potential Vf15 for a predetermined time. The holding waveform element b21 holds the potential Vf15 from the time t152 to a time t153.

The contraction waveform element c21 rises from the potential Vf15 to a potential Vg15 (Vg15>Ve) to contract the individual liquid chamber 106, and thus a liquid droplet is discharged. The contraction waveform element c21 is at the potential Vf15 at the time t153 and rises to the potential Vg15 at a time t154.

The holding waveform element b22 holds the potential Vg15 raised by the contraction waveform element c21 for a predetermined time. The holding waveform element b22 holds the potential Vg15 from the time t154 to a time t155.

The contraction waveform element c22 rises from the potential Vg15 to a potential Vh15 to contract the individual liquid chamber 106, and thus a liquid droplet is discharged. The contraction waveform element c22 is at the potential Vg15 at the time t155 and rises to the potential Vh15 at a time t156.

The holding waveform element b23 holds the potential Vh15 for a predetermined time. The holding waveform element b23 holds the potential Vh15 from the time t156 to a time t157.

The expansion waveform element a22 falls from the potential Vh15 to a potential Vi15 (Vf15<Vi15<Ve) to expand the individual liquid chamber 106. The expansion waveform element a22 is at the potential Vh15 at the time t157 and falls to the potential Vi15 at a time t158.

A time period T151 from the start of the expansion waveform element a21 to the start of the contraction waveform element c21 in the pulse P15 is 0.5 Tc. The time period T151 is from the time t151 to the time t153.

A time period T152 from the start of the contraction waveform element c21 to the start of the contraction waveform element c22 is 0.5 Tc. The time period T152 is from the time t153 to the time t155.

A time period T153 from the end of the contraction waveform element c21 to the end of the contraction waveform element c22 is 0.5 Tc.

A time period T154 from the end of the contraction waveform element c21 to the end of the expansion waveform element a22 is Tc.

With such a pulse P15, a liquid droplet can be discharged at a high speed. Further, the residual vibration due to the contraction waveform element c21 can be reduced or prevented by the contraction waveform element c22.

However, with the pulse P15 according to Comparative Example 1, the tail of the discharged droplet cannot be torn off and then returned to the inside of the nozzle. Accordingly, a satellite droplet of mist cannot be sufficiently reduced.

The waveform for large droplets according to Comparative Example 1 includes the pulses P1, P2, P13, P4, and P15. The waveform for small droplets according to Comparative Example 1 includes the pulse P13.

Example 1, Example 2, and Comparative Example 1 The result of measuring a satellite length when a droplet is discharged using the drive waveform of Example 1, Example 2, and Comparative Example 1 is described below. The drive waveform Pv of Example 1 is the drive waveform Pv of Embodiment 1 described above, which is illustrated in FIG. 8, FIG. 9, and FIG. 14. The drive waveform of Example 2 is the drive waveform Pv of Embodiment 2 described above, and is illustrated in FIG. 8, FIG. 14, and FIG. 15. The drive waveform Pv11 of Comparative Example 1 is illustrated in FIG. 11, FIG. 16, and FIG. 17 as described above. FIG. 12 is a graph illustrating a satellite length when a droplet is discharged using the drive waveforms according to Example 1, Example 2, and Comparative Example 1.

Satellite Length

In FIG. 12, from left to right, the lengths of satellite lengths in a large droplet of Example 1, a large droplet of Example 2, a large droplet of Comparative Example 1, a small droplet of Example 1, a small droplet of Example 2, and a small droplet of Comparative Example 1 are illustrated by a bar chart. The satellite lengths were measured by actual photographing.

The satellite length is measured as a difference (Tjs−Tj) between a time Tj and a time Tjs. The time Tj is a time when a main droplet (a leading large droplet) of a discharged droplet reaches the position of the sheet 42. The time Tjs is a time when the tail portion of the main droplet or a small droplet that reaches the position of the sheet 42 after the main droplet reaches the position of the sheet 42. For this reason, the satellite length is expressed in time (s).

The satellite length in the small droplet of Comparative Example 1 was about 100 s. The satellite length in the small droplet of Example 1 was about 40 s. The satellite length in the droplet of Example 1 was shorter than the satellite length in the droplet of Comparative Example 1. The satellite length in the small droplet of Example 2 was about 60 s. The satellite length in the small droplet of Example 1 was shorter than the satellite length in the small droplet of Example 2.

From the measurement result, it was confirmed that the satellite length can be shortened by using the pulse P3 for discharging the small droplet of Example 1 and Example 2. In other words, it was confirmed that the satellite length can be shortened by setting the time period T**32** from the start of the first contraction waveform element c**31** to the start of the second expansion waveform element a**32** of the pulse P**3** to be less than 0.5 Tc and setting the time period T**33** from the start of the first contraction waveform element c**31** to the start of the second contraction waveform element c**32** to 0.5 Tc.

The satellite length in the large droplet of Comparative Example 1 was about 350 s. The satellite length in the large droplet of Example 1 was about 98 s. The satellite length in the large droplet of Example 2 was about 140 s. The satellite lengths in the large droplets of Example 1 and Example 2 were shorter than the satellite length in the large droplet of Comparative Example 1.

From the measurement result, it was confirmed that the satellite length can be shortened by using the pulse P**5** for discharging the large droplet of Example 1 and Example 2. In other words, it was confirmed that the satellite length of the large droplet can be shortened by setting the time period T**2** from the start of the first contraction waveform element c**1** to the start of the second expansion waveform element a**2** of the pulse P**5**, which is the final pulse, to be less than 0.5 Tc and setting the time period T**3** from the start of the first contraction waveform element c**1** to the start of the second contraction waveform element c**2** to be within the range from 0.5 Tc to 0.6 Tc.

Further, the satellite length in the large droplet of Example 1 was shorter than the satellite length in the large droplet of Example 2. Accordingly, it was confirmed that the satellite length can be further shortened by setting the time period T**1** from the start of the first expansion waveform element a**1** to the start of the first contraction waveform element c**1** of the pulse P**5** to be within the range from 0.45 Tc to 0.65 Tc and setting the time period T**4** from the start of the first contraction waveform element c**1** to the start of the third expansion waveform element a**3** to be within the range from 0.9 Tc to 1.0 Tc.

In the case of the large droplet of Comparative Example 1, when the frequency is 12 kHz, the main droplet deflected by about several tens of m. The spacing between the nozzles was 169.3 m. In this case, the discharge deflection of the main droplet affects image formation. In the case of the small droplet of Comparative Example 1, no discharge deflection is detected.

In the case of the droplets of Example 1 and Example 2, no discharge deflection is detected. In the case of the large droplets of Example 1 and Example 2, when the frequency is 12 kHz, no deflection of the main droplet was observed. Further, in the case of the large droplets of Example 1 and Example 2, even when the frequency was set to the maximum 24 kHz, no deflection of the main droplet was observed.

The change amount of a sub-scanning speed fluctuation rate is described below with reference to FIG. **13**. FIG. **13** is a graph illustrating the change amount of the sub-scanning speed fluctuation rate. The sub-scanning speed is a speed at which a medium is conveyed. In the following description, the speed at which a medium is conveyed is referred to as a "conveyance speed of medium" or a "conveyance speed." During the use of the image forming apparatus **1**, when mist of liquid droplets adheres to an encoder that detects the conveyance speed of a medium, the conveyance speed of a medium fluctuates. As the number of printed sheets increases, the change amount of the sub-scanning speed fluctuation rate gradually deteriorates. Specifically, the difference between the actual conveyance speed and the measured conveyance speed increases.

FIG. **13** illustrates the relation between the number of printed sheets and the degree of soil of the encoder (the change amount of the sub-scanning speed fluctuation rate) when printing is performed by the actual apparatus. In FIG. **13**, the horizontal axis represents the number of printed sheets, and the vertical axis represents the change amount of the sub-scanning speed fluctuation rate. The dirtier the encoder, the larger the value of the change amount of the sub-scanning speed fluctuation rate.

In the measurement experiment, in order to increase soil, the distance between the surface of a nozzle plate of the recording head and a medium was increased compared to a normal operation condition to increase the amount of soil. A chart used for the printing typically contains figures and text, and the large droplet, the medium droplet, and the small droplet were all used.

The waveform for large droplets, the waveform for medium droplets, the waveform for small droplets, and the waveform for micro drive of Example 1 are illustrated in FIG. **8**, FIG. **9**, and FIG. **14**, as described above. The waveform for large droplets, the waveform for medium droplets, the waveform for small droplets, and the waveform for micro drive of Example 2 are illustrated in FIG. **8**, FIG. **14**, and FIG. **15**, as described above.

The waveform for large droplets, the waveform for medium droplets, the waveform for small droplets, and the waveform for micro drive of Comparative Example 1 are illustrated in FIG. **11**, FIG. **16**, and FIG. **17**, as described above. The waveform for micro drive of Comparative Example 1 is the pulse P**1**, and is the same as the waveform for micro drive of Example 1 and Example of 2. The waveform for medium droplets of Comparative Example 1 includes the pulse P**2** and the pulse P**4**, and is the same as the waveform for medium droplet of Example 1 and Example 2.

The change amount of the sub-scanning speed fluctuation rate is a deterioration amount of fluctuation in reading by the encoder, and deteriorates due to soil by mist in the apparatus. When mist adheres to the encoder, soil accumulates.

When the soil of the encoder is accumulates, the scale on the encoder is not read accurately, and thus a medium is not conveyed accurately. As a result, the image forming apparatus becomes unusable.

In the case of Example 1, when the number of printed sheets was 2000, the change amount of the sub-scanning speed fluctuation rate (%) was less than or equal to 0.5%. In the case of Example 2, when the number of printed sheets was 2000, the change amount of the sub-scanning speed fluctuation rate (%) was less than or equal to 1.5%. In the case of Comparative Example 1, when the number of printed sheets was 500, the change amount of the sub-scanning speed fluctuation rate was about 2.0%. In the case of Comparative Example 1, when the number of printed sheets was 1000, the change amount of the sub-scanning speed fluctuation rate was about 3.2%.

In Example 1, the encoder is less dirty than in Comparative Example 1, and thus the life of the apparatus can be extended. In Example 1 and Example 2, the encoder is less dirty than in Comparative Example 1, and the conveyance speed is accurately maintained. Thus, deterioration in print quality is reduced or prevented.

Further, the change amount of the sub-scanning speed fluctuation rate (%) in Example 1 is smaller than the change amount of the sub-scanning speed fluctuation rate (%) in Example 2. Accordingly, it was confirmed that the generation of mist can be further reduced and that the soil of the encoder is reduced by setting the time period T**1** from the start of the first expansion waveform element a**1** to the start of the first contraction waveform element c**1** of the pulse P**5** to be within the range from 0.45 Tc to 0.65 Tc and setting the time period T**4** from the start of the first contraction waveform element c**1** to the start of the third expansion waveform element a**3** to be within the range from 0.9 Tc to 1.0 Tc. As a result, in Example 1, the encoder is less soiled and the conveyance speed is accurately maintained. Thus, deterioration in print quality is reduced or prevented.

In the present disclosure, the term "sheet" refers to not only a sheet of paper but also a material onto which ink droplets or other liquid can adhere. For example, the sheet includes an overhead projector (OHP) transparency, fabric, glass, or a substrate. The term "medium" in the present disclosure is used as a synonym of, for example, a recorded medium, a recording medium, a recording paper, or a recording sheet.

Further, the term "image forming apparatus" refers to an apparatus to form an image by discharging liquid onto a medium made of, for example, paper, thread, fiber, fabric, leather, metals, plastics, glass, wood, or ceramics. The term "image formation" also refers to an action for providing (i.e., printing) not only meaningful images, such as characters and figures, on a medium but also meaningless images such as patterns on the medium (the term "image formation" includes causing liquid droplets to land on the medium).

The term "ink" refers to not only to "ink" in a narrow sense, unless specified, but also to a generic term for any types of liquid usable for image formation. For example, the term "ink" includes recording liquid, fixing solution, and liquid. The "ink" includes, for example, deoxyribonucleic acid (DNA) sample, resist, and pattern material.

The term "image" is not limited to a two-dimensional image and includes, for example, an image applied to a three-dimensional object and a three-dimensional object itself formed as a three-dimensionally fabricated image.

The term "image forming apparatus," unless specified, also includes both serial-type image forming apparatus and line-type image forming apparatus.

Although some embodiments and variation have been described above, embodiments of the present disclosure are not limited to the above-described embodiments and variation. Various modifications and substitutions may be made to the above-described embodiments without departing from the scope described in the appended claims.

For example, in the above-described embodiments, the image forming apparatus including the recording head has been described. However, the recording head and the control of the recording head according to embodiments of the present disclosure can be widely applied to liquid discharge apparatuses including an image forming apparatus.

In the present disclosure, the "liquid discharge apparatus" is an apparatus that includes a liquid discharge head or a liquid discharge device and drives the liquid discharge head to discharge liquid. The liquid discharge apparatus includes, for example, any apparatus that can discharge liquid to a material onto which liquid can adhere or any apparatus to discharge liquid toward gas or into liquid.

The "liquid discharge apparatus" further includes, for example, devices relating to feeding, conveying, and ejecting of the material onto which liquid can adhere and also include a pretreatment apparatus and an aftertreatment apparatus.

The "liquid discharge apparatus" includes, for example, an image forming apparatus to form an image on a sheet by discharging ink, or a three-dimensional apparatus to discharge fabrication liquid to a powder layer in which powder material is formed in layers, so as to form a three-dimensional object.

The "liquid discharge apparatus" is not limited to an apparatus that discharges liquid to visualize meaningful images such as characters or figures. For example, the liquid discharge apparatus may be an apparatus that forms meaningless images such as meaningless patterns or an apparatus that fabricates three-dimensional images.

The above-described term "material onto which liquid can adhere" refers to a material on which liquid is at least temporarily adhered, a material on which liquid is adhered and fixed, or a material into which liquid is adhered to permeate. Specific examples of the "material onto which liquid can adhere" include, but are not limited to, a recording medium such as a paper sheet, recording paper, a recording sheet of paper, a film, or cloth, an electronic component such as an electronic substrate or a piezoelectric element, and a medium such as layered powder, an organ model, or a testing cell. The "material onto which liquid can adhere" includes any material to which liquid adheres, unless particularly limited.

Examples of the "material onto which liquid can adhere" include any materials to which liquid can adhere even temporarily, such as paper, thread, fiber, fabric, leather, metal, plastic, glass, wood, and ceramic.

Further, the pressure generator used in the "liquid discharge head" is not limited to a particular type of pressure generator. In addition to the piezoelectric actuator (which may use a laminated piezoelectric element), for example, a thermal actuator using a thermoelectric transducer such as a thermal resistor, and an electrostatic actuator including a diaphragm and a counter electrode can be used.

Further, the terms "image formation," "recording," "printing," "image printing," and "fabricating" used in the present disclosure are used synonymously with each other.

The functionality executed by the controller **500** according to the above-described embodiments can be implemented using circuitry or processing circuitry which includes general purpose processors, special purpose processors, integrated circuits, application specific integrated circuits (ASICs), digital signal processors (DSPs), field programmable gate arrays (FPGAs), conventional circuitry and/or combinations thereof which are configured or programmed to perform the disclosed functionality. Processors are considered processing circuitry or circuitry as they include transistors and other circuitry therein. In the disclosure, the circuitry, units, or means are hardware that carry out or are programmed to perform the recited functionality. The hardware may be any hardware disclosed herein or otherwise known which is programmed or configured to carry out the recited functionality. When the hardware is a processor which may be considered a type of circuitry, the circuitry, means, or units are a combination of hardware and software, the software being used to configure the hardware and/or processor.

In the liquid discharge apparatus according to the related art, when a liquid discharge head is driven at a high frequency to discharge liquid droplets, the discharged liquid droplets sometimes deflect since slight vibration remains in liquid in an individual liquid chamber of the liquid discharge head. Further, mist is sometimes generated as the liquid droplets are discharged.

According to one or more embodiments of the present disclosure, a liquid discharge apparatus is provided that can perform high-frequency driving while reducing the generation of mist as liquid droplets are discharged and further preventing deflection of the liquid droplets.

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. 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.

The invention claimed is:

1. A liquid discharge apparatus, comprising:

a liquid discharge head including:

a plurality of nozzles to discharge liquid droplets;

a plurality of individual liquid chambers communicating with the plurality of nozzles; and

a plurality of pressure generators to generate a pressure that pressurizes liquid in the plurality of individual liquid chambers; and

a head drive controller to output, to the plurality of pressure generators, a drive waveform including one pulse or two or more pulses selected according to a droplet size, wherein

in a case that the drive waveform includes the two or more pulses, the drive waveform includes a final pulse at an end of the two or more pulses,

the final pulse includes:

a first expansion waveform element for expanding the plurality of individual liquid chambers;

a first contraction waveform element for contracting the plurality of individual liquid chambers, the first contraction waveform element being subsequent to the first expansion waveform element;

a second expansion waveform element for expanding the plurality of individual liquid chambers, the second expansion waveform element being subsequent to the first contraction waveform element;

a second contraction waveform element for contracting the plurality of individual liquid chambers, the second contraction waveform element being subsequent to the second expansion waveform element; and

a third expansion waveform element for expanding the plurality of individual liquid chambers, the third expansion waveform element being subsequent to the second contraction waveform element,

when a natural vibration period of the plurality of the plurality of individual liquid chambers is defined as Tc,

a time period from a start of the first contraction waveform element to a start of the second expansion waveform element is less than 0.5 Tc, and

a time period from the start of the first contraction waveform element to a start of the second contraction waveform element is within a range from 0.5 Tc to 0.6 Tc.

2. The liquid discharge apparatus of claim 1, wherein

a time period from a start of the first expansion waveform element to the start of the first contraction waveform element is within a range from 0.45 Tc to 0.65 Tc, and

a time period from the start of the first contraction waveform element to a start of the third expansion waveform element is within a range from 0.9 Tc to 1.0 Tc.

3. The liquid discharge apparatus of claim 1, further comprising a conveyor belt to convey a medium on which an image is formed by liquid discharged from the liquid discharge head, wherein

the conveyor belt conveys the medium while attracting the medium with an electrostatic attraction force.

4. Anon-transitory computer-executable medium storing a program storing instructions which, when executed by a processor of a computer, causes the computer to execute processing of discharging liquid from a plurality of nozzles of a liquid discharge head, the processing comprising outputting, to a pressure generator, a drive waveform including one pulse or two or more pulses selected according to a droplet size, wherein

in a case that the drive waveform includes the two or more pulses, the drive waveform includes a final pulse at an end of the two or more pulses,

the final pulse includes:

a first expansion waveform element for expanding a plurality of individual liquid chambers of the liquid discharge head;

a first contraction waveform element for contracting the plurality of individual liquid chambers, the first contraction waveform element being subsequent to the first expansion waveform element;

a second expansion waveform element for expanding the plurality of individual liquid chambers, the second expansion waveform element being subsequent to the first contraction waveform element;

a second contraction waveform element for contracting the plurality of individual liquid chambers, the second contraction waveform element being subsequent to the second expansion waveform element; and

a third expansion waveform element for expanding the plurality of individual liquid chambers, the third expansion waveform element being subsequent to the second contraction waveform element,

when a natural vibration period of the plurality of the plurality of individual liquid chambers is defined as Tc,

a time period from a start of the first contraction waveform element to a start of the second expansion waveform element is less than 0.5 Tc, and

a time period from the start of the first contraction waveform element to a start of the second contraction waveform element is within a range from 0.5 Tc to 0.6 Tc.

5. The non-transitory computer-executable medium of claim 4, wherein

a time period from a start of the first expansion waveform element to the start of the first contraction waveform element is within a range from 0.45 Tc to 0.65 Tc, and

a time period from the start of the first contraction waveform element to a start of the third expansion waveform element is within a range from 0.9 Tc to 1.0 Tc.

6. A method for controlling a driving of a liquid discharge head including a plurality of nozzles to discharge liquid droplets, a plurality of individual liquid chambers communicating with the plurality of nozzles, and a plurality of pressure generators to generate a pressure that pressurizes liquid in the individual liquid chambers, the method comprising outputting, to the plurality of pressure generators, a drive waveform including one pulse or two or more pulses selected according to a droplet size, wherein

in a case that the drive waveform includes the two or more pulses, the drive waveform includes a final pulse at an end of the two or more pulses,

the final pulse includes:

a first expansion waveform element for expanding the plurality of individual liquid chambers;

a first contraction waveform element for contracting the plurality of individual liquid chambers, the first contraction waveform element being subsequent to the first expansion waveform element;

a second expansion waveform element for expanding the plurality of individual liquid chambers, the second expansion waveform element being subsequent to the first contraction waveform element;

a second contraction waveform element for contracting the plurality of individual liquid chambers, the second contraction waveform element being subsequent to the second expansion waveform element; and

a third expansion waveform element for expanding the plurality of individual liquid chambers, the third expansion waveform element being subsequent to the second contraction waveform element,

when a natural vibration period of the plurality of the plurality of individual liquid chambers is defined as Tc,

a time period from a start of the first contraction waveform element to a start of the second expansion waveform element is less than 0.5 Tc, and

a time period from the start of the first contraction waveform element to a start of the second contraction waveform element is within a range from 0.5 Tc to 0.6 Tc.

7. The method of claim **6**, wherein

a time period from a start of the first expansion waveform element to the start of the first contraction waveform element is within a range from 0.45 Tc to 0.65 Tc, and

a time period from the start of the first contraction waveform element to a start of the third expansion waveform element is within a range from 0.9 Tc to 1.0 Tc.

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