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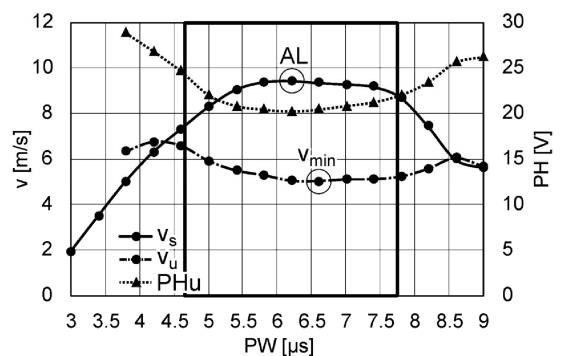
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(54) **LIQUID DISCHARGE HEAD, RECORDING DEVICE, AND METHOD FOR EVALUATING LIQUID DISCHARGE HEAD**

(57) A liquid ejection head comprises a first flow path and an actuator. The first flow path includes an ejection hole configured to eject liquid, a pressurization chamber communicating with the ejection hole, and at least a portion on the pressurization chamber side of a supply path configured to supply the liquid to the pressurization chamber. The actuator is configured to apply pressure to the pressurization chamber. An upper limit of an ejection velocity at which liquid is ejected as one droplet without being divided into satellite droplets for each pulse width in response to a rectangular pulse configured to perform ejection by pull ejection being applied to the actuator is referred to as a single-droplet upper limit velocity, and half of a natural vibration period of liquid in the first flow path is referred to as AL. At this time, in the liquid ejection head, a predetermined condition relating to a minimum value of the single-droplet upper limit velocity in response to the pulse width being within a range of $AL \pm 25\%$ is satisfied.

FIG.6



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Description

TECHNICAL FIELD

[0001] The present disclosure relates to a liquid ejection head such as an inkjet head, a recording apparatus comprising the liquid ejection head, and an evaluation method for a liquid ejection head.

BACKGROUND OF INVENTION

[0002] A liquid ejection head (for example, an inkjet head) that ejects liquid (for example, ink) toward a recording medium (for example, paper) is known (for example, see Patent Literature 1 below). The liquid is ejected as a droplet (for example, an ink droplet) from an ejection hole (nozzle) that the head comprises, lands on the recording medium, and forms a dot. An arbitrary image is formed by forming a plurality of dots.

[0003] Patent Literature 1 raises satellite droplets as a problem. A satellite droplet is a phenomenon in which, in response to one droplet of liquid being intended to be ejected from an ejection hole, a leading portion of the liquid ejected from the ejection hole and a remaining portion separate, resulting in two or more droplets. Patent Literature 1 examines flow path shapes, flow path dimensions, and flow path characteristics so that the probability of satellite droplets occurring is reduced.

CITATION LIST

PATENT LITERATURE

[0004] Patent Literature 1: International Publication No. WO 2010/137435

SUMMARY

[0005] A liquid ejection head according to one aspect of the present disclosure comprises a first flow path and an actuator. The first flow path includes an ejection hole configured to eject liquid, a pressurization chamber communicating with the ejection hole, and at least a portion on the pressurization chamber side of a supply path configured to supply the liquid to the pressurization chamber. The actuator is configured to apply pressure to the pressurization chamber. An upper limit of an ejection velocity at which the liquid is ejected as one droplet without being divided into satellite droplets for each pulse width in response to a rectangular pulse configured to perform ejection by pull ejection being applied to the actuator is referred to as a single-droplet upper limit velocity, and half of a natural vibration period of the liquid in the first flow path is referred to as AL.

[0006] In one example, in the liquid ejection head, a minimum value of the single-droplet upper limit velocity in response to the pulse width being within a range of $AL \pm 25\%$ is 4.0 m/s or more.

[0007] In one example, the liquid ejection head further comprises a driver configured to input a first signal having a pulse height set to a predetermined operating voltage to the actuator. The minimum value of the single-droplet upper limit velocity in response to the pulse width being within the range of $AL \pm 25\%$ is 40.5% or more of an ejection velocity in response to the pulse having the same pulse width as the pulse width at which the minimum value is obtained and the same pulse height as the operating voltage being applied to the actuator.

[0008] In one example, in the liquid ejection head, a ratio $(v_{\max} - v_{\min})/v_{\min}$ of a difference between a minimum value $v_{\min}$ and a maximum value $v_{\max}$ of the single-droplet upper limit velocity in response to the pulse width being within the range of $AL \pm 25\%$ to the minimum value $v_{\min}$ is 0.8 or less.

[0009] In one example, in the liquid ejection head, a quantity of a droplet ejected at the minimum value of the single-droplet upper limit velocity in response to the pulse width being within the range of $AL \pm 25\%$ is 6.5 pL or more.

[0010] A recording apparatus according to one aspect of the present disclosure comprises the liquid ejection head described above and a moving unit configured to relatively move the liquid ejection head and a recording medium.

[0011] In an evaluation method for a liquid ejection head according to one aspect of the present disclosure, the liquid ejection head comprises a first flow path and an actuator. The first flow path includes an ejection hole configured to eject liquid, a pressurization chamber communicating with the ejection hole, and at least a portion on the pressurization chamber side of a supply path configured to supply the liquid to the pressurization chamber. The actuator is configured to apply pressure to the pressurization chamber. An upper limit of an ejection velocity at which the liquid is ejected as one droplet without being divided into satellite droplets for each pulse width in response to a rectangular pulse configured to perform ejection by pull ejection being applied to the actuator is referred to as a single-droplet upper limit velocity, and half of a natural vibration period of the liquid in the first flow path is referred to as AL. At this time, the evaluation method includes a determination of whether or not a minimum value of the single-droplet upper limit velocity in response to the pulse width being within a range of $AL \pm 25\%$ satisfies a predetermined condition.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012]

[FIG. 1] A side view of a recording apparatus according to an embodiment.

[FIG. 2] A plan view of the recording apparatus of FIG. 1.

[FIG. 3] An exploded perspective view showing a

part of a head of the recording apparatus of FIG. 1.

[FIG. 4] A cross-sectional view taken along line IV-IV of FIG. 3.

[FIG. 5] A diagram for explaining an ejection operation of the head of FIG. 4.

[FIG. 6] A diagram for explaining a single-droplet upper limit velocity.

[FIG. 7] A diagram for explaining high-frequency vibration in a descender.

[FIG. 8] A diagram showing a condition relating to an absolute value of a minimum value of a single-droplet upper limit velocity.

[FIG. 9] A diagram showing a condition relating to a relative value of a minimum value of a single-droplet upper limit velocity.

[FIG. 10] A diagram showing a condition relating to a variation amount of a single-droplet upper limit velocity.

[FIG. 11] A diagram showing a condition relating to a droplet quantity in response to a single-droplet upper limit velocity being at a minimum value.

[FIG. 12] A diagram showing a relationship between high-frequency vibration in a descender and a minimum value of a single-droplet upper limit velocity.

[FIG. 13] A diagram showing a relationship between a position of a changing portion of a descender and a minimum value of a single-droplet upper limit velocity.

[FIG. 14] A diagram showing a relationship between a length of a changing portion of a descender and a minimum value of a single-droplet upper limit velocity.

[FIG. 15] A diagram showing a relationship between a diameter of a changing portion of a descender and a minimum value of a single-droplet upper limit velocity.

[FIG. 16] Another diagram showing a relationship between a diameter of a changing portion of a descender and a minimum value of a single-droplet upper limit velocity.

[FIG. 17] Another diagram showing a relationship between inertance of a descender and a minimum value of a single-droplet upper limit velocity.

[FIG. 18] Another diagram showing a relationship between compliance of a descender and a minimum value of a single-droplet upper limit velocity.

5 [FIG. 19] A diagram showing frequencies of main vibration and high-frequency vibration in examples.

DESCRIPTION OF EMBODIMENTS

10 **[0013]** Hereinafter, embodiments according to the present disclosure will be described with reference to the drawings. The drawings used in the following description are schematic. Therefore, for example, dimensional ratios and the like in the drawings do not necessarily match actual ones. Dimensional ratios and the like may not match between drawings. A specific shape and/or dimension and the like may be exaggerated, or details may be omitted. However, the above does not deny that an actual shape and/or dimension may be as shown in the drawings, or that features of a shape and/or dimension may be extracted from the drawings.

15 **[0014]** For convenience, an orthogonal coordinate system D1D2D3 is attached to the drawings, and terms such as D1 direction, D2 direction, and D3 direction may be used. The liquid ejection head and recording apparatus according to the embodiment may be used in any orientation. However, for convenience, terms assuming the +D3 side as upward may be used.

20 (Overview of Embodiment)

25 **[0015]** In the present embodiment, a new concept of "single-droplet upper limit velocity" is introduced. With this new concept, a configuration of a liquid ejection head can be defined, or characteristics of a liquid ejection head can be evaluated. Specifically, it is as follows.

30 **[0016]** FIG. 4 is a cross-sectional view showing a part of a head 3 (reference numeral refers to FIG. 1; an example of a liquid ejection head) according to the embodiment. The diagram on the right side of FIG. 4 shows another example regarding a part of the diagram on the left side of FIG. 4.

35 **[0017]** On a lower surface (ejection surface 5) of the head 3, an ejection hole 7 configured to eject liquid (for example, ink) is opened. A droplet (ink droplet) ejected downward from the ejection hole 7 lands on a recording medium (not shown) (see printing paper P in FIG. 1 to be described later), whereby a dot constituting an image is formed.

40 **[0018]** The head 3 comprises, as flow paths communicating with the ejection hole 7, for example, in order from the ejection hole 7, a descender 9, a pressurization chamber 11, and a supply path 13. A part of the supply path 13 is a restrictor 15 that narrows a cross section (a cross section orthogonal to a flow direction) of the supply path 13. A flow path from the restrictor 15 to the ejection hole 7 may be referred to as a first flow path 17.

45 **[0019]** An upper surface of the pressurization chamber

11 is covered by an actuator 19. In response to pressure being applied to the pressurization chamber 11 by the actuator 19, liquid is pushed out from the pressurization chamber 11 toward the ejection hole 7. Consequently, a droplet is ejected from the ejection hole 7. The pressurization chamber 11 that has pushed out the liquid is replenished with liquid from the supply path 13.

[0020] FIG. 5 shows an example of a drive signal Sg1 input to the actuator 19. In this diagram, a horizontal axis indicates a normalized time t/AL obtained by dividing time t by AL (Acoustic Length). AL is half of a natural vibration period of the liquid in the first flow path 17. A left vertical axis indicates a potential V of the drive signal Sg1.

[0021] The drive signal Sg1 includes, for example, a rectangular pulse Ps. This pulse Ps is configured to eject a droplet by so-called pull ejection, as will be described later. A time length of the pulse Ps is referred to as a pulse width PW. A variation amount (amplitude) of a potential of the pulse Ps is referred to as a pulse height PH.

[0022] FIG. 6 is a diagram for explaining a single-droplet upper limit velocity. In this diagram, a horizontal axis indicates a pulse width PW (μs). A left vertical axis indicates an ejection velocity v (m/s) of a droplet ejected from the ejection hole 7. A right vertical axis indicates a pulse height PH (V). This diagram is obtained from experiments.

[0023] A reference velocity v_s plotted in FIG. 6 is an ejection velocity v in response to the pulse height PH being set to a predetermined operating voltage (to be described later). As is publicly known, the ejection velocity v (v_s) changes in response to a change in the pulse width PW. In response to the pulse width PW being AL (approximately $6.2 \mu s$ in the illustrated example), the ejection velocity v (v_s) becomes maximum. In FIG. 6, a range of $AL \pm 25\%$ (a range of approximately $4.65 \mu s$ to approximately $7.75 \mu s$ in the illustrated example) is surrounded by a frame.

[0024] Here, in response to the pulse width PW being a constant value, the higher the pulse height PH, the higher the ejection velocity v . Also, the higher the ejection velocity v , the higher the probability that satellite droplets occur. Therefore, by performing ejection while changing the pulse height PH and determining whether or not satellite droplets have occurred, an upper limit of the ejection velocity v at which satellite droplets do not occur can be specified. This upper limit of the ejection velocity v is defined as "single-droplet upper limit velocity." The single-droplet upper limit velocity is a value obtained for each pulse width PW.

[0025] In FIG. 6, a single-droplet upper limit velocity v_u is plotted. Also, a single-droplet upper limit voltage PHu, which is the pulse height PH in response to the single-droplet upper limit velocity v_u being obtained, is plotted. Among the single-droplet upper limit velocities v_u , a minimum value v_{min} within the range of $AL \pm 25\%$ is circled.

[0026] The head 3 (shape and dimensions of flow paths, etc.) according to the embodiment is configured,

for example, so that a predetermined condition relating to the minimum value v_{min} is satisfied. As the predetermined condition, for example, the following are mentioned.

Conditions A to D may be adopted alone, or two or more may be adopted in combination.

Condition A: The minimum value v_{min} is 4.0 m/s or more.

Condition B: The minimum value v_{min} is 40.5% or more of a reference velocity v_s having the same pulse width PW as the minimum value v_{min} .

Condition C: In response to a maximum value among the single-droplet upper limit velocities v_u within the range of $AL \pm 25\%$ being v_{max} , a ratio $(v_{max} - v_{min})/v_{min}$ is 0.8 or less.

Condition D: A quantity of a droplet ejected at the minimum value v_{min} is 6.5 pL or more.

[0027] By comprising the configuration as described above, for example, adjustment of a waveform of the drive signal Sg1 is facilitated. Specifically, it is as follows.

[0028] As described above, in a process of obtaining the single-droplet upper limit velocity v_u , a rectangular pulse Ps is used. On the other hand, a waveform of the drive signal Sg1 actually used is usually not a rectangular pulse Ps. The waveform of the drive signal Sg1 is adjusted so that states of various evaluation items such as a quantity of a droplet, an ejection velocity, and/or presence or absence (and degree thereof) of satellite droplets fall within desired ranges.

[0029] Among the evaluation items of droplets as described above, which is emphasized differs depending on required image quality, a type of recording medium (for example, paper or cloth, etc.), a distance between the head 3 and the recording medium, and the like. For example, some satellite droplets may be allowed. However, in general, a degree (number and quantity) of satellite droplets is preferably small.

[0030] Here, even in response to adjusting the waveform of the drive signal Sg1, it may be difficult or impossible to bring states of other evaluation items within desired ranges while eliminating satellite droplets or keeping a degree of satellite droplets within an allowable range. This can be evaluated as the head 3 not comprising a structure (for example, a shape and dimensions of the first flow path 17) that can widely allow such adjustment. Conventionally, the head 3 has not been manufactured from a viewpoint of such ease of adjustment.

[0031] In a configuration in which at least one of the conditions A to D relating to the single-droplet upper limit velocity described above is satisfied, a probability that the above-described inconvenience occurs is reduced. For example, in response to increasing the pulse height PH to

increase a quantity of a droplet, the ejection velocity v also increases. As a result, a probability that satellite droplets occur increases. However, in response to the condition A being satisfied (that is, in response to the minimum value $v_{\min}$ being relatively large), the ejection velocity v after increasing the pulse height PH does not exceed the single-droplet upper limit velocity v_u , or even in response to exceeding, a difference therebetween is unlikely to become large. As a result, satellite droplets do not occur, or a degree of satellite droplets is reduced.

[0032] The above is an overview of the embodiment. Hereinafter, details of the embodiment will be described generally in the following order.

1. Printer in general (FIGS. 1 and 2)
2. Head (FIGS. 3 to 5)
 - 2.1. Overall configuration of head
 - 2.2. Flow path member
 - 2.2.1. Flow path member in general
 - 2.2.2. Individual flow path
 - 2.2.3. Changing portion of descender
 - 2.3. Actuator substrate
 - 2.4. Ejection operation
3. Examples
 - 3.1. Explanation of parameters (FIGS. 6 and 7)
 - 3.2. Measurement method
 - 3.3. Specifications of examples and comparative examples
 - 3.4. Single-droplet upper limit velocity in examples and comparative examples
 - 3.4.1. Regarding condition A (FIG. 8)
 - 3.4.2. Regarding condition B (FIG. 9)
 - 3.4.3. Regarding condition C (FIG. 10)
 - 3.4.4. Regarding condition D (FIG. 11)
 - 3.4.5. Regarding f_2/f_1 (FIGS. 8 to 11 and FIG. 19)
 - 3.4.6. Regarding B2/B1 (FIG. 12)
 - 3.4.7. Regarding dimensions and characteristics including changing portion (FIGS. 13 to 18)
4. Summary of embodiment

(1. Printer in General)

[0033] FIG. 1 is a side view of a printer 1 comprising a head 3. FIG. 2 is a plan view of the printer 1.

[0034] A configuration of the printer 1 may be various configurations except for a configuration relating to the head 3 (furthermore, a portion thereof directly related to ejection of droplets), and may be, for example, a publicly known configuration. The printer 1 illustrated in FIGS. 1 and 2 is merely an example. Hereinafter, taking the printer 1 shown in FIGS. 1 and 2 as an example, the printer 1 in general will be briefly described.

[0035] The printer 1 forms an image on printing paper P by ejecting ink droplets downward from the head 3. The printing paper P is conveyed by a conveying device 21. The head 3 and the conveying device 21 are controlled by a controller 23 (FIG. 1).

[0036] The printer 1 is configured as a so-called line printer. That is, a head unit 25 including at least one head 3 (five in the example of FIG. 2) extends over substantially an entire width of the printing paper P (a length in a direction (D1 direction) intersecting a conveying direction (D2 direction) of the printing paper P). In response to the printing paper P being conveyed, printing is performed on a band-shaped region extending in the D1 direction, and consequently, a two-dimensional image is formed.

[0037] In each head unit 25, five heads 3 are arranged in a staggered manner so that no gap is generated in the D1 direction as viewed in the D2 direction. In each head unit 25, a configuration for fixing a plurality of heads 3 to each other is arbitrary. In FIGS. 1 and 2, a frame (reference numeral omitted) comprising an opening (not shown) that exposes an ejection surface 5 of the head 3 downward is illustrated.

[0038] The printer 1 is not limited to a line printer. For example, the printer 1 may be a serial printer. In a serial printer, for example, an operation of printing while moving a head (head unit) in a direction intersecting a conveying direction of the printing paper P and conveying of the printing paper P are alternately performed.

[0039] The printer 1 comprises a total of four head units 25. The four head units 25 are, for example, arranged in a conveying direction of the printing paper P. Five heads 3 in each head unit 25 correspond to ink of the same color. The four head units 25 correspond to inks of mutually different colors (inks of four colors). The inks of four colors are, for example, magenta (M), yellow (Y), cyan (C), and black (K). Thereby, the printer 1 functions as a color printer.

[0040] Unlike the above description, the printer 1 may perform printing of a single color, or conversely, may perform printing of more than four colors. That is, a number of colors is arbitrary. Also, two or more head units 25 may correspond to one color. Conversely, one head unit 25 may correspond to two or more colors, for example, by one head 3 corresponding to two or more colors. A number of heads 3 included in one head unit 25 is arbitrary and may be one. As understood from the

above, a number of heads 3 that the printer 1 comprises is arbitrary.

[0041] The printer 1 performs printing, for example, on roll paper as the printing paper P. However, the printing paper P may be cut sheet paper. Also, a size of the printing paper P is also arbitrary. For example, a size of the printing paper P may be small like a receipt, may be a size generally used in an office, or may be large like a poster.

[0042] A configuration of the conveying device 21 is arbitrary. In FIGS. 1 and 2, a configuration in which the printing paper P is conveyed by rotating a roller sandwiching the printing paper P is illustrated. As another configuration, for example, a configuration in which the printing paper P is conveyed by conveying a belt on which the printing paper P is adsorbed, or a configuration in which the printing paper P is conveyed by rotating a drum around which the printing paper P is wound, is mentioned. The conveying device 21 is, in a broader concept, a moving unit configured to relatively move the head (3) and a recording medium (P).

[0043] The controller 23 is configured, for example, to include a computer, and controls the head 3 and the conveying device 21 based on print data including data of an image (assumed to be a broad concept including characters).

[0044] The printer 1 may comprise various components in addition to the above-described components. Although not particularly illustrated, examples are given below.

- Drying device: For example, promotes drying of ink.
- Coating device: For example, uniformly coats a transparent coating agent on the printing paper P.
- Cleaning device: For example, performs cleaning of the head 3.

The printer 1 may use the head 3 for coating of a coating agent in addition to or instead of printing with ink having color.

(2. Head)

(2.1. Overall Configuration of Head)

[0045] FIG. 3 is an exploded perspective view showing a part of the head 3. The head 3 comprises, for example, a substantially plate-shaped head main body 27, at least one (two in the illustrated example) FPC 29 connected to the head main body 27, and at least one (five in the illustrated example) drive IC 31 (an example of a driver; IC: Integrated Circuit) mounted on each FPC 29.

[0046] The head main body 27 comprises a flow path member 33 comprising the first flow path 17 described above, and an actuator substrate 35 including the actuator 19. The head main body 27 may be regarded as an

example of a head. The drive IC 31 generates the drive signal Sg1 described above based on a signal from the controller 23. The FPC 29 transmits a signal from the controller 23 to the driver 31 and transmits a signal (for example, the drive signal Sg1) from the driver 31 to the actuator substrate 35.

[0047] A configuration of the head 3 may be various configurations except for a configuration relating to the head main body 27, and may be, for example, a publicly known configuration. Therefore, for example, numbers, arrangement positions, specific configurations, and the like of the FPC 29 and the drive IC 31 are arbitrary. Also, the head main body 27 may be configured in various ways as long as a condition relating to a single-droplet upper limit velocity (for example, at least one of conditions A to D) is satisfied. Therefore, for example, a basic structure excluding details of a shape and dimensions and the like may be the same as a publicly known structure.

[0048] Also, the head 3 may comprise appropriate components in addition to the components illustrated in FIG. 3. Although not particularly illustrated, examples of other components are given below.

- Back parts: For example, overlap a non-arrangement region of the actuator substrate 35 on an upper surface of the flow path member 33, and supply ink to the flow path member 33.
- Housing: For example, covers the back parts from above so as to accommodate the FPC 29 and the drive IC 31.
- Heat sink: For example, constitutes a part of a side surface of the housing, contacts the drive IC 31, and contributes to heat dissipation of the drive IC 31.
- Circuit board: For example, is located inside the housing, mediates between the controller 23 and the FPC 29, and comprises various electric circuits.
- Connector: For example, is exposed from the housing and mediates between the controller 23 and the circuit board.

(2.2. Flow Path Member)

(2.2.1. Flow Path Member in General)

[0049] As described above, the head main body 27 may be configured in various ways as long as a condition relating to a single-droplet upper limit velocity (for example, at least one of conditions A to D) is satisfied. In the illustrated example, it is as follows.

[0050] The flow path member 33 is a substantially plate-shaped member. The flow path member 33 comprises, as flow paths, at least one (eight in the illustrated example) port 37, at least one (four in the illustrated

example) common flow path 39, and a plurality of individual flow paths 41 (only a part is shown). Each individual flow path 41 comprises the first flow path 17 described above. Ink flows in order of the port 37, the common flow path 39, and the individual flow path 41, and is ejected from the ejection hole 7.

[0051] The port 37 is opened on a back surface (upper surface) of the flow path member 33. A plurality of common flow paths 39 extend from the port 37 along the ejection surface 5 inside the flow path member 33, and extend in parallel with each other. A plurality of individual flow paths 41 are arranged along each common flow path 39 and over substantially an entire length of the common flow path 39. However, in FIG. 6, for convenience, only a part of the individual flow paths 41 (furthermore, only the pressurization chamber 11, which is a part of each individual flow path 41) is shown. Also, the individual flow paths 41 should be indicated by dotted lines like the common flow paths 39, but for convenience, they are indicated by solid lines because they are small compared to a size of the diagram.

[0052] A number of common flow paths 39 and a direction in which they extend are arbitrary, and a number of ports 37 and opening positions are also arbitrary. In the example of FIG. 3, the common flow paths 39 extend along (for example, in parallel with) a longitudinal direction (D1 direction) of the flow path member 33. The ports 37 are connected to both ends of the common flow paths 39. From another viewpoint, the ports 37 are located on a short side side of the flow path member 33 with respect to the common flow paths 39 (from another viewpoint, the actuator substrate 35). Ink flows from both ends of the common flow paths 39 toward a center.

[0053] Examples other than the illustrated example are given. A direction in which a plurality of common flow paths 39 extend may be the D2 direction instead of the D1 direction, or may be a direction inclined at an angle of 45° or less with respect to the D1 direction or the D2 direction. One or more common flow paths 39 extending along the D1 direction may be arranged in the D1 direction. A plurality of common flow paths 39 may merge at one end or both ends to constitute a manifold-shaped flow path. That is, a plurality of common flow paths 39 do not have to be independent of each other inside the flow path member 33 one by one. The port 37 may be located on a long side side of the flow path member 33 with respect to the common flow paths 39 (and/or the actuator substrate 35). The port 37 may be connected to only one end instead of being connected to both ends of the common flow paths 39. Ink may flow from one end of the common flow paths 39 toward another end.

[0054] A plurality of ejection holes 7 (from another viewpoint, a plurality of individual flow paths 41) are arranged in one or more rows (for example, two rows or four rows) along each common flow path 39, and are arranged in a plurality of rows (in other words, two-dimensionally) on the ejection surface 5 by a plurality of common flow paths 39 being provided in parallel with

each other. Thereby, a plurality of ejection holes 7 are densely arranged as viewed in a conveying direction of the printing paper P, so that a resolution of a printed image is improved. The ejection holes 7 may be provided in one row.

[0055] FIG. 4 is a cross-sectional view taken along line IV-IV of FIG. 3. This diagram shows a range corresponding to, roughly, one common flow path 39 (a cross section thereof) and one individual flow path 41 (a longitudinal section thereof).

[0056] The flow path member 33 is configured, for example, by laminating a plurality of plates 43. In the plates 43, a plurality of voids (for example, through holes and recesses) constituting flow paths are formed. Thicknesses and a number of laminations of the plurality of plates 43 may be appropriately set according to a shape of flow paths and the like. The plurality of plates 43 may be formed of an appropriate material. For example, the plurality of plates 43 are formed of metal or resin. A thickness of the plates 43 is, for example, 10 μm or more and 300 μm or less. The plates 43 are fixed to each other by, for example, an adhesive (for example, a thermosetting resin) (not shown) interposed between the plates 43.

(2.2.2. Individual Flow Path)

[0057] The individual flow path 41 includes, for example, a flow path from the supply path 13 described above to the ejection hole 7. Specific shapes and dimensions of these respective parts are arbitrary. In the illustrated example, it is as follows.

[0058] The pressurization chamber 11 is, for example, opened on an upper surface of the flow path member 33 and is closed by the actuator 19. The pressurization chamber 11 may be closed by the plate 43. In any case, the pressurization chamber 11 is located above the ejection hole 7 and the descender 9. A shape of the pressurization chamber 11 may be appropriately set. For example, the pressurization chamber 11 is formed in a thin shape that spreads with a constant thickness along an upper surface of the flow path member 33. However, the pressurization chamber 11 may comprise portions having different thicknesses. A thin shape is, for example, a shape in which a thickness is smaller than any diameter in plan view. Also, for example, a planar shape of the pressurization chamber 11 may be a shape (for example, a rhombus or an ellipse) comprising a longitudinal direction and a lateral direction orthogonal to each other, or may be a shape (for example, a circle) in which such directions cannot be conceptualized.

[0059] The descender 9 extends from a lower surface of the pressurization chamber 11 toward the ejection surface 5. A shape of the descender 9 is roughly cylindrical. The descender 9 may be parallel to the D3 direction, or may be inclined with respect to the D3 direction in a part or as a whole. In the illustrated example, substantially the whole is parallel to the D3 direction. However, an upper part is inclined so as to be separated from the pressur-

ization chamber 11 to a side opposite to the supply path 13. A cross-sectional area of the descender 9 may be constant in a length direction of the descender 9, or may differ depending on a position in the length direction (illustrated example). In plan view (as viewed in the D3 direction), the descender 9 is connected to, for example, an end portion of the pressurization chamber 11 in a predetermined direction (for example, a longitudinal direction of the pressurization chamber 11 in plan view).

[0060] The ejection hole 7 is opened in a part of a bottom surface of the descender 9. The ejection hole 7 is located, for example, at substantially a center of a bottom surface of the descender 9. However, the ejection hole 7 may be provided eccentrically with respect to a center of a bottom surface of the descender 9. A shape of a longitudinal section of the ejection hole 7 is tapered so that a diameter becomes smaller toward the ejection surface 5 side. However, the ejection hole 7 may be inversely tapered in part or in whole.

[0061] The supply path 13 extends upward from an upper surface of the common flow path 39, then extends in a direction along the plate 43, and then extends upward and is connected to a lower surface of the pressurization chamber 11. A portion extending in a direction along the plate 43 is the restrictor 15. A shape of the supply path 13 is, for example, cylindrical except for the restrictor 15. The restrictor 15 has, for example, a substantially rectangular cross-sectional shape, and extends along an appropriate path (for example, linearly or curvedly) as viewed in the D3 direction. The restrictor 15 has a smallest cross-sectional area in the supply path 13, and has, for example, a smallest cross-sectional area in the individual flow path 41 except for the ejection hole 7. As viewed in the D3 direction, a connection position of the supply path 13 to the pressurization chamber 11 is, for example, an end portion on a side opposite to the descender 9 with respect to a center of a lower surface of the pressurization chamber 11.

[0062] Although not particularly illustrated, examples of shapes of the individual flow path 41 different from the illustrated example are given below.

[0063] For example, the individual flow path 41 may comprise a recovery path configured to recover liquid from the descender 9. The recovery path may connect an appropriate position of the descender 9 and a common flow path for recovery (a flow path different from the common flow path 39). As understood from the above, the head 3 (printer 1) may circulate liquid.

[0064] Also, for example, the individual flow path 41 may comprise a dead-end flow path (side branch) extending from the descender 9. Also, the individual flow path 41 may comprise a bypass connecting mutually different positions of the descender 9. Such a side branch or bypass contributes to, for example, reduction of high-frequency vibration (to be described later) in the descender 9.

[0065] Also, for example, the individual flow path 41 may not comprise the descender 9. For example, the

ejection hole 7 may be directly opened on a lower surface of the pressurization chamber 11.

(2.2.3. Changing Portion of Descender)

[0066] The descender 9 illustrated in FIG. 4 comprises a changing portion 45 in which a cross-sectional area changes. The changing portion 45 is a narrow portion (example on the left of FIG. 4) in which a cross-sectional area is smaller than portions before and after it, or a wide portion (example on the right of FIG. 4) in which a cross-sectional area is larger than portions before and after it. In response to such a changing portion 45 being provided, for example, high-frequency vibration to be described later becomes easier to attenuate. As a result, a probability that satellite droplets caused by high-frequency vibration occur can be reduced.

[0067] As reference numerals are attached to a diagram on the right of FIG. 4, a portion of the descender 9 on the pressurization chamber 11 side with respect to the changing portion 45 is referred to as a first communication path 9a. A portion on the ejection hole 7 side with respect to the changing portion 45 is referred to as a second communication path 9b. Symbols L1, L2, and L3 are used for flow path lengths of the first communication path 9a, the second communication path 9b, and the changing portion 45, respectively. Symbols S1, S2, and S3 are used for cross-sectional areas of the first communication path 9a, the second communication path 9b, and the changing portion 45, respectively. Examples of specific values of L1 to L3 and S1 to S3 will be described later.

[0068] A flow path length (L1 to L3) is a length in a direction in which liquid flows. In FIG. 4, for convenience, a symbol L1 is attached in parallel to the D3 direction. In response to the descender 9 being inclined with respect to the D3 direction, a flow path length may be, for example, a length of a line passing through a center of a cross section of the descender 9. When specifying a length of a line passing through a center of a cross section and a cross-sectional area (S1 to S3), the cross section may be a cross section orthogonal to the D3 direction. The same applies in response to calculating inertance and compliance to be described later.

(2.3. Actuator Substrate)

[0069] A number, shape, and dimensions of the actuator substrate 35 are arbitrary. In the example of FIG. 3, one actuator substrate 35 comprising a width extending over all pressurization chambers 11 is provided. A shape of the actuator substrate 35 is roughly rectangular comprising four sides parallel to four sides of the flow path member 33, and a longitudinal direction is also the same as a longitudinal direction of the flow path member 33. Unlike the illustrated example, for example, a plurality of actuator substrates 35 may be arranged in a longitudinal direction of the flow path member 33.

[0070] As reference numerals are attached to FIG. 4, the actuator substrate 35 comprises the actuator 19 described above for each pressurization chamber 11. The actuator 19 is, for example, a piezo type that applies pressure to ink by mechanical distortion of a piezoelectric body. A piezo type actuator is, for example, a so-called unimorph type. The actuator 19 may be configured by a piezo type actuator of another type such as a bimorph type.

[0071] A unimorph type actuator 19 comprises, for example, in order from the flow path member 33 side, a vibration plate 47, a common electrode 49, a piezoelectric layer 51, and an individual electrode 53. The vibration plate 47, the common electrode 49, and the piezoelectric layer 51 roughly spread over an entirety of the actuator substrate 35, for example. That is, these are provided in common to a plurality of pressurization chambers 11. The individual electrode 53 is provided for each pressurization chamber 11. The individual electrode 53 comprises a main body portion 53a overlapping the pressurization chamber 11, and a lead-out electrode 53b drawn out from the main body portion 53a and to which a drive signal is input. The main body portion 53a roughly comprises the same shape and dimensions as a shape and dimensions of the pressurization chamber 11. Specific materials and thicknesses of respective layers are arbitrary.

[0072] At least a portion of the piezoelectric layer 51 sandwiched between the main body portion 53a of the individual electrode 53 and the common electrode 49 is polarized in a thickness direction. Therefore, for example, in response to an electric field (voltage) being applied in a polarization direction of the piezoelectric layer 51 by the main body portion 53a and the common electrode 49, the piezoelectric layer 51 contracts in a direction along the layer. This contraction is restricted by the vibration plate 47. As a result, the actuator 19 bends and deforms so as to be convex toward the pressurization chamber 11 side. In response to an electric field (voltage) being applied in a direction opposite to the above by the main body portion 53a and the common electrode 49, the actuator 19 bends and deforms to a side opposite to the pressurization chamber 11. By using such bending deformation, a volume of the pressurization chamber 11 can be changed, and pressure can be applied to ink in the pressurization chamber 11.

[0073] The FPC 29 (FIG. 3) is, for example, arranged so that a region on one end side thereof faces the actuator substrate 35, and a pad (not shown) located on a surface of the region is connected to the lead-out electrode 53b. The drive signal Sg1 generated by the drive IC 31 is input to the lead-out electrode 53b via the FPC 29. Also, the actuator substrate 35 comprises a connection electrode (not shown) connected to the common electrode 49 at an appropriate position (for example, outside an arrangement region of a plurality of pressurization chambers 11). The FPC 29 comprises a pad (not shown) connected to the connection electrode. A constant potential (for ex-

ample, a reference potential) is applied to the common electrode 49 from the FPC 29.

(2.4. Ejection Operation)

[0074] As described with reference to FIG. 5, the head main body 27 inputs the pulse Ps to the actuator 19 and performs a so-called pull ejection type ejection operation. The pulse Ps is rectangular as in the illustrated example in specifying a single-droplet upper limit velocity, and is set to an appropriate shape in actual use. Even in the latter case, a main principle is the same as in a case of a rectangular pulse Ps. Hereinafter, a pull ejection type will be described taking a rectangular pulse Ps as an example.

[0075] A horizontal axis and a left vertical axis of FIG. 5 are as already described. A right vertical axis indicates a displacement x and a velocity u of a meniscus (a liquid surface in the ejection hole 7). On a right vertical axis, a + side (upper side in the diagram) indicates a displacement x and a velocity u toward an outside side (-D3 side) of the ejection hole 7. Lines Lx and Lu indicate temporal changes of the displacement x and the velocity u, respectively. In actuality, a timing at which a drive signal is applied and the actuator 19 starts to be displaced and a timing at which a meniscus starts to be displaced are shifted by a propagation time for pressure to propagate through a flow path, but in FIG. 5, the shift is excluded. The same applies to the following description, and it is described as if there is no propagation time.

[0076] In the description here, in response to a potential of the individual electrode 53 being higher than a potential of the common electrode 49, an electric field is applied to the piezoelectric layer 51 in the same direction as a polarization direction, and the actuator 19 is in a shape bent toward the pressurization chamber 11 side. However, a level of potentials at the individual electrode 53 and the common electrode 49 in response to bending the actuator 19 toward the pressurization chamber 11 side may be opposite to the description here.

[0077] Before there is an ejection request, the drive signal Sg1 (from another viewpoint, the individual electrode 53) is set to a potential higher than the common electrode 49 (hereinafter, "high potential V_H"). In response to there being an ejection request, a potential of the individual electrode 53 is set to a potential lower than the high potential V_H (hereinafter, "low potential V_L"), and then set to the high potential V_H again at a predetermined timing. Thereby, the pulse Ps is input to the individual electrode 53. The low potential V_L may be appropriately set, but is, for example, the same potential as the common electrode 49.

[0078] Before an ejection request, the drive signal Sg1 is set to the high potential V_H, whereby the actuator 19 is in a shape bent toward the pressurization chamber 11 side. A displacement x of a meniscus at this time is set to zero. Also, a velocity u of a meniscus at this time is basically or ideally zero.

[0079] Next, in response to the drive signal Sg1 becoming the low potential V_L (t/AL=0), the actuator 19 starts to return to a shape before deformation (a flat shape), and a volume of the pressurization chamber 11 increases. Consequently, a negative pressure (-P) is applied to liquid in the pressurization chamber 11. Thereby, a meniscus is displaced toward an inside side of the ejection hole 7, and an absolute value of a velocity relating to this displacement increases. Also, from another viewpoint, liquid in the individual flow path 41 (first flow path 17) starts to vibrate at a natural vibration period.

[0080] Thereafter, an absolute value of a velocity of a meniscus reaches a peak (t/AL=approximately 0.5) and starts to decrease. Furthermore, in response to t/AL becoming approximately 1, a volume of the pressurization chamber 11 becomes maximum, and a pressure becomes a positive pressure (P) substantially opposite to a pressure applied at t/AL=0. At this time, a displacement x of a meniscus is located most toward an inside side of the ejection hole 7, and a velocity u becomes approximately zero. Next, a volume of the pressurization chamber 11 starts to decrease, and a pressure decreases.

[0081] In response to the drive signal Sg1 becoming the high potential V_H after being set to the low potential V_L, the actuator 19 starts to bend toward the pressurization chamber 11 side again. A vibration first applied by a fall of the pulse Ps and a vibration next applied by a rise of the pulse Ps overlap, and a larger pressure is applied to liquid. This pressure propagates through the descender 9 and causes liquid to be ejected from the ejection hole 7. In response to a pulse width PW of the drive signal Sg1 being AL, in response to t/AL being approximately 1 and a pressure of the pressurization chamber 11 being a positive pressure (P), a positive pressure (P) is further applied by the actuator 19, so that a pressure of 2P propagates through the descender 9.

[0082] That is, a droplet can be ejected by supplying the pulse Ps that becomes the low potential V_L for a certain period with the high potential V_H as a reference to the individual electrode 53. In response to a pulse width PW of the pulse Ps being set to half a time (AL) of a natural vibration period of liquid in the first flow path 17, in principle, a maximum value (maximum velocity u_{max}) of a velocity u becomes maximum. Consequently, an ejection velocity v (FIG. 6) and an ejection quantity of liquid become maximum.

[0083] A rectangular pulse Ps in response to obtaining a single-droplet upper limit velocity does not have to be a strict rectangle. For example, an error that is unavoidable in a configuration of a circuit that generates the pulse Ps may occur. For example, a fall and a rise may comprise an unavoidable inclination with respect to a vertical axis. For example, each of a fall and a rise may require a time of 2.0 μs or less and/or 35% or less of AL. In response to an inclination existing as described above, a pulse width PW may be, for example, a time length from a start of a fall to a start of a rise.

[0084] A drive signal Sg1 in response to actually using the head 3 may be adjusted, for example, in a pulse width PW and a pulse height PH. Also, for example, an inclination of a fall and/or a rise of the pulse Ps with respect to a vertical axis may be adjusted. Also, for example, the drive signal Sg1 may be adjusted to include a waveform that reduces residual fluctuation of a meniscus. The waveform may be a part of the pulse Ps, may be connected to the pulse Ps, or may be separated from the pulse Ps.

[0085] Shading intended in an image (including characters) formed on a recording medium may be realized by an appropriate method. For example, it may be realized by a size of a dot diameter on a recording medium, may be realized by a change (density) in a number of dots per constant area, or may be a combination thereof. A size of a dot diameter may be adjusted by a size of one droplet, may be adjusted by a number of droplets landing at one location, or may be a combination thereof.

[0086] Also, from another viewpoint, intended shading may be realized by a size of a droplet ejected from the ejection hole 7 adjusted by a potential difference between a high potential V_H and a low potential V_L of the drive signal Sg1 and the like, may be realized by an increase or decrease in a number of droplets adjusted by a number of pulses Ps included in the drive signal Sg1 corresponding to one ejection request, may be realized by an increase or decrease in a number per constant area of ejection holes 7 (actuators 19 to which the pulse Ps is input) that perform an ejection operation, or may be realized by a combination thereof.

(3. Examples)

[0087] A plurality of head main bodies 27 according to a plurality of examples and a plurality of comparative examples were manufactured, and an experiment for measuring a single-droplet upper limit velocity was performed. Results thereof are shown below. Hereinafter, for example, it is shown that conditions A to D relating to a single-droplet upper limit velocity are not satisfied in a conventional head.

(3.1. Explanation of Parameters)

[0088] Terms and/or parameters used in descriptions of examples and comparative examples will be described.

[0089] "Main vibration" refers to natural vibration of liquid in the first flow path 17. "High-frequency vibration" refers to natural vibration of liquid in the descender 9. A frequency of main vibration is f₁, and a frequency of high-frequency vibration is f₂. AL is half of a period of main vibration, and is (1/f₁)/2.

[0090] FIG. 7 is a diagram showing an example of an amplitude spectrum of a velocity in vibration of a meniscus. In this diagram, a horizontal axis indicates a frequency f (kHz). A vertical axis indicates an intensity I of a spectrum, and more specifically, indicates an amplitude

A (m/s) of a velocity.

[0091] As shown in this diagram, vibration of a meniscus is composed of vibrations of various frequencies being combined (can be regarded as such). Vibrations of various frequencies include main vibration and high-frequency vibration. An intensity becomes high at a frequency corresponding to each of main vibration and high-frequency vibration and a vicinity thereof (see frequencies relating to B1 and B2).

[0092] A maximum value of a portion where an intensity becomes high as described above is referred to as a peak intensity. A peak intensity relating to main vibration is B1, and a peak intensity relating to high-frequency vibration is B2. A frequency corresponding to a peak intensity B1 is a frequency f1 of main vibration. A frequency corresponding to a peak intensity B2 is a frequency f2 of high-frequency vibration.

[0093] Peak intensities B1 and B2 may be specified, for example, as follows. The following specification method is also used in analysis of examples and comparative examples.

[0094] In a head 3 to be measured, an experiment is performed in which a drive signal Sg1 comprising a fall of a rectangular pulse Ps (not comprising a rise) is input to the actuator 19. At this time, a velocity u of a meniscus is measured by a laser Doppler vibrometer. In measurement, a laser is irradiated onto a meniscus from outside through the ejection hole 7. Then, a frequency of a reflected laser is detected. Thereby, a temporal change (from another viewpoint, a waveform of vibration) of a velocity u of a meniscus is obtained.

[0095] An obtained waveform includes waveforms of various frequencies such as a waveform due to main vibration and a waveform due to high-frequency vibration. This waveform is decomposed into waveforms for each frequency by Fourier transform (for example, FFT: fast Fourier transform). Thereby, a spectrum as illustrated in FIG. 7 can be obtained.

[0096] In an obtained spectrum, a highest one among maximum values of intensity is a peak intensity B1 of main vibration. On a higher frequency side than a peak intensity B1, a maximum value of intensity that is second highest after a peak intensity B1 is a peak intensity B2 of high-frequency vibration. A noise-like maximum value may be appropriately excluded, and peak intensities B1 and B2 may be specified.

[0097] AL may be obtained from a frequency f1 corresponding to a peak intensity B1 specified as described above. In FIG. 6, for convenience, "AL" is attached to a plot at which a reference velocity v_s becomes maximum (that is, a position different from AL obtained from the above specification method).

[0098] "Operating voltage" is a pulse height PH of a pulse Ps actually used in the head 3. In an aspect in which a plurality of types of pulses Ps having mutually different pulse heights PH are used to realize various densities and the like, a maximum pulse height PH may be an operating voltage. Also, in response to a pulse Ps not

being rectangular, a maximum potential difference (V_H-V_L) in the pulse Ps may be a pulse height PH. Also, before use of the head 3, a maximum value of a pulse height PH for appropriately using the head 3 described in a specification or an instruction manual may be specified as an operating voltage. In examples and comparative examples, an operating voltage is 26 V.

[0099] "M1" refers to a combined inertance of the pressurization chamber 11 and the first communication path 9a of the descender 9. "M2" refers to a combined inertance of the second communication path 9b and the ejection hole 7 of the descender 9. "M2/M1" is a ratio of both. In analysis of examples and comparative examples, a combined inertance was specified based on an equation $M = \rho L / S$. Here, M is inertance, ρ is a density of liquid, L is a length of a flow path, and S is a cross-sectional area of a flow path.

[0100] "C1" refers to a combined compliance of the pressurization chamber 11 and the first communication path 9a of the descender 9. "C2" refers to a combined compliance of the second communication path 9b and the ejection hole 7 of the descender 9. "C2/C1" is a ratio of both. In analysis of examples and comparative examples, a combined compliance was specified based on an equation $C = W / \rho c^2$. Here, C is compliance, W is a volume of a flow path, ρ is a density of liquid, and c is a sound velocity of liquid.

(3.2. Measurement Method)

[0101] A rectangular pulse Ps was input to the actuator 19 of a prototyped head main body 27 to eject ink. Specifications of ink are as follows.

- Density: approximately 1.10 g/cm³
- Sound velocity: approximately 1500 m/s
- Surface tension: approximately 37 mN/m
- Viscosity: approximately 7 mPa·S

[0102] A droplet was photographed in a range in which a distance from the ejection surface 5 is 0.9 mm to 1.1 mm. Based on a photographing result, an ejection velocity v was calculated. Also, an image obtained by photographing the above range (0.9 mm to 1.1 mm) was visually observed to determine whether or not it was one droplet. In response to liquids being connected to some extent within the above range, it was determined to be one droplet.

[0103] Then, a pulse height PH was changed in increments of 0.2 V (that is, an ejection velocity v was changed), and an upper limit (that is, a single-droplet upper limit velocity v_u) of an ejection velocity v at which one droplet is ejected was obtained. Also, a pulse width PW was changed in increments of 0.4 μ s within an appropriate wide range including a range of $AL \pm 25\%$, and a

minimum value $v_{\min}$ (and a maximum value $v_{\max}$) of a single-droplet upper limit velocity v_u within a range of $AL \pm 25\%$ was obtained. Such calculation of a minimum value $v_{\min}$ was performed for each of head main bodies 27 according to examples and comparative examples.

[0104] As illustrated in FIG. 6, in this experiment, a single-droplet upper limit velocity v_u became smaller as a pulse width PW was closer to AL, and this tendency was the same even in a relatively wide range including a range of $AL \pm 25\%$. In other words, a minimum value $v_{\min}$ obtained in a range of $AL \pm 25\%$ was also a minimum value of a single-droplet upper limit velocity v_u in a relatively wide range. From another viewpoint, in this experiment, accuracy of specifying AL did not affect specifying a minimum value $v_{\min}$.

[0105] In response to changing a pulse width PW in a range of 0 to 2AL and ejecting, basically, ejection occurs in a range narrower than $AL \pm 50\%$. In response to a minimum value of a single-droplet upper limit velocity v_u being within a range of $AL \pm 25\%$, it is considered that an influence of high-frequency vibration on vibration as a whole is not excessive. In response to such being the case, it is considered that satellite droplets are unlikely to occur even in actual use.

(3.3. Specifications of Examples and Comparative Examples)

[0106] A basic configuration of head main bodies according to examples and comparative examples is substantially the same as a configuration of a head main body 27 according to an embodiment described so far. However, unlike a shape illustrated in FIG. 4, an entirety of the descender 9 is parallel to the D3 direction. That is, a flow path length of the descender 9 and a length of the descender 9 in the D3 direction are the same. Also, a planar shape of the pressurization chamber 11 is a rhombus shape in which corners are chamfered by arcs.

[0107] A plurality of examples and a plurality of comparative examples differ only in a shape and dimensions of the descender 9, and other conditions are the same as each other. Specifically, it is as follows.

- ref0 (comparative example): The descender 9 does not comprise a changing portion 45.
- ref1 (comparative example): The descender 9 comprises a narrow portion (changing portion 45). Various dimensions basically follow values disclosed in Patent Literature 1.
- smp (example or comparative example): The descender 9 comprises a changing portion 45 (narrow portion or wide portion). At least a part of various dimensions is not disclosed in Patent Literature 1.

[0108] Values of specifications common to examples and comparative examples are shown below.

- Depth of pressurization chamber 11: 50 μm
- Length of pressurization chamber 11 in D2 direction (see FIG. 4) (length of a long diagonal of a chamfered rhombus): 838 μm
- Length of pressurization chamber 11 in D1 direction (see FIG. 4) (length of a short diagonal of a chamfered rhombus): 519 μm
- Diameter of ejection hole 7: 22 μm
- Length of ejection hole 7: 50 μm

[0109] In Patent Literature 1, an experiment is performed by changing a depth of the pressurization chamber 11 and a diameter of the ejection hole 7 with the above length of the ejection hole 7 (50 μm). A combination of the above depth of the pressurization chamber 11 and diameter of the ejection hole 7 (50 μm and 22 μm) is one obtained when the highest evaluation was obtained regarding single-droplet formation.

[0110] Values of specifications of ref0 (comparative example) are shown below.

- L0: 1290 μm
- Minimum value of diameter of descender: 180 μm
- Maximum value of diameter of descender: 220 μm
- Average value of diameter of descender: approximately 209 μm

[0111] Values of specifications of ref1 (comparative example) are shown below. In S3/S1, S3 is constant in the D1 direction (the same applies to smp). Average values in the D1 direction were used for S1 and S2 (the same applies to smp).

- L0: 790 μm
- Minimum value of diameter of descender (excluding narrow portion): 180 μm
- Maximum value of diameter of descender (excluding narrow portion): 200 μm
- Average value of diameter of descender (excluding narrow portion): approximately 185 μm
- L2/L0: approximately 0.20
- L3/L0: approximately 0.13
- S3/S1: approximately 0.56
- S3/S2: approximately 0.60

[0112] In Patent Literature 1, an experiment is performed by changing L2/L0 and L3/L0 with the above L0 (790 μm). A highest evaluation regarding single-droplet formation is obtained when L2/L0 is 0.20 to 0.40 and L3/L0 is 0.10 to 0.15. Furthermore, in Patent Literature 1, an experiment is performed by changing S3/S1 and L3/L0 with L2/L0 set to 0.30. A highest evaluation regarding single-droplet formation is obtained when S3/S1 is 0.30 to 0.70 and L3/L0 is 0.10 to 0.15.

[0113] A plurality of smp (examples or comparative examples) are configurations in which a changing portion 45 is provided in ref0. A plurality of smp differ from each other in a position (D3 direction), a length (D3 direction), and a diameter of a changing portion 45. Values of specifications thereof are shown below.

- L2/L0: approximately 0.16 to approximately 0.63
- L3/L0: approximately 0.04 to approximately 0.35
- S3/S1: approximately 0.15 to approximately 1.86
- S3/S2: approximately 0.15 to approximately 1.80

[0114] In a plurality of smp, a diameter of a narrow portion is basically a minimum diameter of the descender 9. Also, a wide portion is basically a maximum diameter of the descender 9. However, a few smp that are not limited thereto are also included.

(3.4. Single-Droplet Upper Limit Velocity in Examples and Comparative Examples)

(3.4.1. Regarding Condition A)

[0115] FIG. 8 is a diagram showing experimental results regarding condition A. In this diagram, a horizontal axis indicates a ratio f_2/f_1 of a frequency f_2 of high-frequency vibration to a frequency f_1 of main vibration. A vertical axis indicates a minimum value $v_{\min}$ of a single-droplet upper limit velocity v_u in response to a pulse width PW being within a range of $AL \pm 25\%$.

[0116] "ref0" and "ref1" in a legend are as already described. "NG" indicates ones among a plurality of smp in which a minimum value $v_{\min}$ became lower than ref0. That is, "NG" indicates ones in which characteristics focusing only on a magnitude of a minimum value $v_{\min}$ deteriorated as a result of providing a changing portion 45. In a legend, ones in which a range of a minimum value $v_{\min}$ is shown indicate ones among a plurality of smp in which a minimum value $v_{\min}$ became higher than ref0. The same applies to FIGS. 9 to 18 to be described later.

[0117] As shown in this diagram, in response to condition A ($v_{\min} \geq 4.0$ m/s) being satisfied, a minimum value $v_{\min}$ is higher than minimum values $v_{\min}$ of ref0 and ref1. Condition A may be further tightened, and a minimum value $v_{\min}$ may be 4.2 m/s or more. This value is realized in a range ($4.15 \leq f_2/f_1 \leq 4.43$) sur-

rounded by a frame. Also, a condition may be further tightened, and a minimum value $v_{\min}$ may be 4.6 m/s or more or 5.0 m/s or more. In this case, a minimum value $v_{\min}$ is roughly a maximum value that can be realized.

[0118] Plots in a diagram are drawn by spreadsheet software based on values before rounding off measured values and the like. On the other hand, a frame is drawn based on values after rounding off measured values and the like and by eye measurement. Therefore, a plot that should be regarded as being located inside a frame may be located slightly outside a frame. The same applies to FIGS. 9 to 18 to be described later.

(3.4.2. Regarding Condition B)

[0119] FIG. 9 is a diagram showing experimental results regarding condition B. In this diagram, a horizontal axis is the same as FIG. 8. A vertical axis indicates a ratio (%) of a minimum value $v_{\min}$ to a corresponding reference velocity v_{sc} . A corresponding reference velocity v_{sc} is an ejection velocity v (among reference velocities v_s shown in FIG. 6, one corresponding to the same pulse width PW as a pulse width PW of a minimum value $v_{\min}$) in response to using a rectangular pulse P_s comprising the same pulse width PW as a pulse width PW in response to a minimum value $v_{\min}$ being obtained and the same pulse height PH as an operating voltage described above.

[0120] As shown in this diagram, in response to condition B ($v_{\min}/v_{sc} \times 100 \geq 40.5$) being satisfied, a ratio $v_{\min}/v_{sc}$ is higher than ratios $v_{\min}/v_{sc}$ of ref0 and ref1. Condition B may be further tightened, and the ratio may be 45% or more. This value is realized in a range ($4.15 \leq f_2/f_1 \leq 4.43$) surrounded by a frame. Also, a condition may be further tightened, and the ratio may be 50% or more or 55% or more. In this case, the ratio is roughly a maximum value that can be realized.

(3.4.3. Regarding Condition C)

[0121] FIG. 10 is a diagram showing experimental results regarding condition C. In this diagram, a horizontal axis is the same as FIG. 8. A vertical axis indicates a ratio $(v_{\max} - v_{\min})/v_{\min}$.

[0122] As shown in this diagram, in response to condition C ($(v_{\max} - v_{\min})/v_{\min} \leq 0.8$) being satisfied, a ratio $(v_{\max} - v_{\min})/v_{\min}$ is smaller than ratios $(v_{\max} - v_{\min})/v_{\min}$ of ref0 and ref1. This value is realized in a range ($4.15 \leq f_2/f_1 \leq 4.43$) surrounded by a frame. Condition C may be further tightened, and the ratio may be 0.4 or less or 0.2 or less. In this case, the ratio is roughly a maximum value that can be realized.

(3.4.4. Regarding Condition D)

[0123] FIG. 11 is a diagram showing experimental results regarding condition D. In this diagram, a horizontal axis is the same as FIG. 8. A vertical axis indicates a

quantity Q_c of a droplet ejected in response to an ejection velocity v being a minimum value $v_{\min}$.

[0124] As shown in this diagram, in response to condition D ($Q_c > 6.5$ pL) being satisfied, Q_c is larger than Q_c of ref0 and ref1. This value is realized in a range ($4.15 \leq f_2/f_1 \leq 4.43$) surrounded by a frame. Condition D may be further tightened, and Q_c may be 7 pL or more or 7.5 pL or more. In this case, Q_c is roughly a maximum value that can be realized.

(3.4.5. Regarding f_2/f_1)

[0125] As understood from FIGS. 8 to 11, in response to a ratio f_2/f_1 of a frequency f_2 of high-frequency vibration to a frequency f_1 of main vibration falling within a specific range, a probability that conditions A to D are satisfied increases. Therefore, for example, f_2/f_1 may be 4.15 or more and 4.43 or less as shown by frames in FIGS. 8 to 11. In this range, a probability that conditions A to D are satisfied increases.

[0126] Also, the above range ($4.15 \leq f_2/f_1 \leq 4.43$) does not include f_2/f_1 of ref0 and ref1. Specifically, f_2/f_1 of ref0 is smaller than the above range, and furthermore, is smaller than f_2/f_1 of any smp. f_2/f_1 of ref1 is larger than the above range, and furthermore, is larger than f_2/f_1 of any smp.

[0127] FIG. 19 is a diagram showing frequencies f_1 and f_2 of ref0, ref1, and smp. In this diagram, a horizontal axis indicates a frequency f_1 . A vertical axis indicates a frequency f_2 . In a legend, "ref0" and "ref1" are as already described. Other legends indicate a range of f_2/f_1 .

[0128] As shown in this diagram, in smp, compared to ref0, f_1 is lower by a changing portion 45 being provided. Thereby, f_2/f_1 of smp is larger than f_2/f_1 of ref0. Also, in smp, compared to ref1, f_2 is lower. Thereby, f_2/f_1 of smp is smaller than f_2/f_1 of ref1. As a reason why f_2 of smp is lower than ref1, it is mentioned that an entire length (L_0) of a descender 9 of smp is longer than ref1.

[0129] From the above, for example, f_1 may be 67 kHz or more and 72 kHz. Also, f_2 may be 292 kHz or more and 306 kHz or less.

(3.4.6. Regarding B_2/B_1)

[0130] FIG. 12 is a diagram showing a relationship between a ratio B_2/B_1 of a peak intensity B_1 of main vibration and a peak intensity B_2 of high-frequency vibration and a minimum value $v_{\min}$. Specifically, in FIG. 8, a horizontal axis is replaced with B_2/B_1 . A legend is basically the same as FIG. 8. However, ref1 is not shown.

[0131] As shown in this diagram, in response to B_2/B_1 being 0.19 or more and 0.29 or less, a probability that a minimum value $v_{\min}$ becomes 4.0 m/s or more increases, and furthermore, a probability that it becomes 4.2 m/s or more or 4.6 m/s or more increases.

(3.4.7. Regarding Dimensions and Characteristics Including Changing Portion)

[0132] FIGS. 13 to 18 are diagrams showing a relationship between specifications of a changing portion 45 and a minimum value $v_{\min}$. Specifically, FIGS. 13 to 18 are ones in which, in FIG. 8, a horizontal axis is replaced with L_2/L_0 , L_3/L_0 , S_3/S_1 , S_3/S_2 , M_2/M_1 , or C_2/C_1 , respectively. A legend is basically the same as FIG. 8. However, ref1 is not shown. Also, ref0 in which a changing portion 45 does not exist is not shown.

[0133] In each diagram, the following ranges are surrounded by frames.

FIG. 13: $0.16 \leq L_2/L_0 \leq 0.51$

FIG. 14: $0.04 \leq L_3/L_0 \leq 0.19$

FIG. 15: $0.23 \leq S_3/S_1 \leq 1.86$

FIG. 16: $0.22 \leq S_3/S_2 \leq 1.80$

FIG. 17: $0.22 \leq M_2/M_1 \leq 0.41$

FIG. 18: $0.15 \leq C_2/C_1 \leq 0.72$

[0134] In response to specifications relating to a changing portion 45 being in the above ranges, a probability that a minimum value $v_{\min}$ becomes 4.0 m/s or more increases, and furthermore, a probability that it becomes 4.2 m/s or more or 4.6 m/s or more increases.

[0135] M_2/M_1 may be 0.26 or more and 0.41 or less, which is narrower than the above range. This range does not overlap at all with a range of M_2/M_1 described in claim 1 of Patent Literature 1, and includes values of M_2/M_1 of many smp.

[0136] C_2/C_1 may be 0.24 or more and 0.72 or less, which is narrower than the above range. This range does not overlap at all with a range of C_2/C_1 described in claim 1 of Patent Literature 1, and includes values of C_2/C_1 of many smp.

(4. Summary of Embodiment)

[0137] As described above, a liquid ejection head (head 3) according to an embodiment comprises a first flow path 17 and an actuator 19. The first flow path 17 includes an ejection hole 7 configured to eject liquid, a pressurization chamber 11 communicating with the ejection hole 7, and at least a portion on the pressurization chamber 11 side of a supply path 13 configured to supply liquid to the pressurization chamber 11. The actuator 19 is configured to apply pressure to the pressurization chamber 11. An upper limit of an ejection velocity v at which liquid is ejected as one droplet without being divided into satellite droplets for each pulse width PW in response to a rectangular pulse P_s configured to perform ejection by pull ejection being applied to the actuator 19 is referred to as a single-droplet upper limit velocity v_u . Half of a natural vibration period of liquid in the first flow path 17 is referred to as AL. At this time, a minimum value $v_{\min}$ of a single-droplet upper limit velocity v_u in response to a pulse width PW being within a range of AL

$\pm 25\%$ may be 4.0 m/s or more (FIG. 8). That is, condition A may be satisfied.

[0138] In this case, a minimum value $v_{\min}$ is relatively large. Therefore, for example, as described in an explanation of an overview of an embodiment, a probability that a drive signal Sg1 can be adjusted so that states of other evaluation items (for example, a quantity of a droplet and/or an ejection velocity) fall within desired ranges while eliminating satellite droplets or keeping a degree of satellite droplets within an allowable range is improved. Also, 4.0 m/s is larger than minimum values $v_{\min}$ of ref0 and ref1. Therefore, compared to a conventional one, a head 3 in which adjustment of a drive signal Sg1 is easy is provided.

[0139] The head 3 may comprise a driver (drive IC 31) configured to input a first signal (pulse Ps not necessarily limited to being rectangular) having a pulse height PH set to a predetermined operating voltage to the actuator 19. A minimum value $v_{\min}$ of a single-droplet upper limit velocity v_u in response to a pulse width PW being within a range of $AL \pm 25\%$ may be 40.5% or more of an ejection velocity v in response to a pulse Ps (a rectangular one similar to in response to obtaining a single-droplet upper limit velocity) comprising the same pulse width PW as a pulse width PW in response to the minimum value $v_{\min}$ being obtained and the same pulse height PH as the operating voltage being applied to the actuator 19 (FIG. 9). That is, instead of or in addition to condition A, condition B ($v_{\min}/v_{sc} \times 100 \geq 40.5$) may be satisfied.

[0140] In this case, a minimum value $v_{\min}$ has a relatively large relative value with respect to an ejection velocity using an operating voltage. Therefore, for example, similarly to in response to condition A being satisfied, a probability that a drive signal Sg1 can be adjusted so that states of other evaluation items fall within desired ranges while eliminating satellite droplets or keeping a degree of satellite droplets within an allowable range is improved. Also, 40.5% is larger than $v_{\min}/v_{sc} \times 100$ of ref0 and ref1. Therefore, compared to a conventional one, a head 3 in which adjustment of a drive signal Sg1 is easy is provided.

[0141] A ratio $(v_{\max} - v_{\min})/v_{\min}$ of a difference between a minimum value $v_{\min}$ and a maximum value $v_{\max}$ of a single-droplet upper limit velocity v_u in response to a pulse width PW being within a range of $AL \pm 25\%$ to the minimum value $v_{\min}$ may be 0.8 or less (FIG. 10). That is, instead of or in addition to conditions A and/or B, condition C may be satisfied.

[0142] In this case, it can be said that a single-droplet upper limit velocity v_u has a small variation amount with respect to a change in a pulse width PW in a range of $AL \pm 25\%$. Therefore, for example, in response to adjusting a pulse width PW, a probability that presence or absence of satellite droplets or a degree of satellite droplets changes greatly is reduced. Also, 0.8 is smaller than $(v_{\max} - v_{\min})/v_{\min}$ of ref0 and ref1. Therefore, compared to a conventional one, a head 3 in which adjustment of a drive signal Sg1 is easy is provided.

[0143] A quantity Qc of a droplet ejected at a minimum value $v_{\min}$ of a single-droplet upper limit velocity v_u in response to a pulse width PW being within a range of $AL \pm 25\%$ may be 6.5 pL or more (FIG. 11). That is, instead of or in addition to conditions A, B, and/or C, condition D may be satisfied.

[0144] In this case, a quantity Qc of a droplet corresponding to a minimum value $v_{\min}$ is relatively large. Therefore, for example, in response to adjusting a drive signal Sg1 so as to increase a quantity of a droplet, an ejection velocity v does not exceed a single-droplet upper limit velocity v_u , or even in response to exceeding, a difference therebetween is unlikely to become large. As a result, for example, a probability that a drive signal Sg1 can be adjusted so that a quantity of a droplet falls within a desired range while eliminating satellite droplets or keeping a degree of satellite droplets within an allowable range is improved. Also, 6.5 pL is larger than Qc of ref0 and ref1. Therefore, compared to a conventional one, a head 3 in which adjustment of a drive signal Sg1 is easy is provided.

[0145] The head 3 may further comprise a descender 9 extending from the pressurization chamber 11 to the ejection hole 7. A ratio f_2/f_1 of a natural vibration frequency f_2 of liquid in the descender 9 to a natural vibration frequency f_1 of liquid in the first flow path 17 may be 4.15 or more and 4.43 or less (FIGS. 8 to 11).

[0146] When the applicant examined a single-droplet upper limit velocity v_u (and a minimum value $v_{\min}$) for examples and comparative examples in which values of various parameters differ from each other, it was found that various parameters (factors) complexly affect a single-droplet upper limit velocity v_u . However, as understood from a comparison of FIGS. 8 to 18, an influence that f_2/f_1 exerts on a single-droplet upper limit velocity v_u is relatively high. When f_2/f_1 is within the above range, for example, a probability that conditions A to D are satisfied is high. From another viewpoint, for example, a probability that a drive signal Sg1 can be adjusted so that a quantity of a droplet falls within a desired range while eliminating satellite droplets or keeping a degree of satellite droplets within an allowable range is improved. Furthermore, the above range of f_2/f_1 is greatly deviated from f_2/f_1 of ref1. Therefore, compared to a conventional one, a head 3 in which adjustment of a drive signal Sg1 is easy is provided.

[0147] As a reason why f_2/f_1 of smp is smaller than ref1, for example, it is mentioned that L0 is longer than ref1, and consequently, f_2 is low. Therefore, from another viewpoint, for example, L0 may be 800 μm or more or 1000 μm or more, and/or may be 5 times or more or 6 times or more of an average diameter of a portion excluding a changing portion 45 of the descender 9.

[0148] In an amplitude spectrum of a vibration velocity of a meniscus of liquid at the ejection hole 7, a ratio B2/B1 of a peak intensity B2 of natural vibration of liquid in the descender 9 to a peak intensity B1 of natural vibration of liquid in the first flow path 17 may be 0.19 or more and

0.29 or less (FIG. 12).

[0149] In this case, for example, a probability that conditions A to D are satisfied is high. Also, for example, in response to B2/B1 being in the above range or more, an influence that f_2/f_1 exerts on a single-droplet upper limit velocity v_u becomes large. As a result, for example, it becomes easy to satisfy conditions A to D by adjusting f_2/f_1 .

[0150] The descender 9 may comprise a changing portion 45 in which a cross-sectional area becomes narrower or wider. A length of the descender 9 is L_0 . A length of a first communication path 9a between the pressurization chamber 11 and the changing portion 45 is L_1 . A length of a second communication path 9b between the changing portion 45 and the ejection hole 7 is L_2 . A cross-sectional area of the first communication path 9a is S_1 . A cross-sectional area of the second communication path 9b is S_2 . A cross-sectional area of the changing portion 45 is S_3 . A combined inertance of the pressurization chamber 11 and the first communication path 9a is M_1 , and a combined compliance is C_1 . A combined inertance of the ejection hole 7 and the second communication path 9b is M_2 , and a combined compliance is C_2 . At this time, the following inequalities may be satisfied.

$$0.16 \leq L_2/L_0 \leq 0.51,$$

$$0.04 \leq L_3/L_0 \leq 0.19,$$

$$0.23 \leq S_3/S_1 \leq 1.86,$$

$$0.22 \leq S_3/S_2 \leq 1.80,$$

$$0.22 \leq M_2/M_1 \leq 0.41,$$

and

$$0.15 \leq C_2/C_1 \leq 0.72.$$

[0151] In this case, for example, a probability that conditions A to D are satisfied is high. Also, the above ranges include values in a plurality of smp for a large number of parameters that have a relatively high influence on satellite droplets. Therefore, for example, a probability that results similar to a plurality of smp are obtained is high.

[0152] A recording apparatus (printer 1) according to an embodiment may comprise a head 3 according to an embodiment as described above and a moving unit (conveying device 21) configured to relatively move the head 3 and a recording medium (printing paper P). In this case, for example, an image in which deterioration of image quality due to satellite droplets is reduced can be obtained.

[0153] In an evaluation method for a liquid ejection

head (head 3) according to an embodiment, the head 3 comprises a first flow path 17 and an actuator 19 configured to apply pressure to a pressurization chamber 11. The evaluation method includes a step of determining whether or not a minimum value $v_{\min}$ of a single-droplet upper limit velocity v_u in response to a pulse width PW being within a range of $AL \pm 25\%$ satisfies a predetermined condition (for example, at least one of conditions A to D).

[0154] Therefore, for example, a prototyped head 3 can be evaluated from a new viewpoint of whether or not it is a head 3 in which it is easy to adjust a drive signal Sg_1 while suppressing satellite droplets, and a design change of the head 3 can be performed. That is, a head 3 in which adjustment of a drive signal Sg_1 is easy can be provided.

[0155] A technology according to the present disclosure is not limited to the above embodiments, and may be implemented in various aspects.

[0156] A recording apparatus may be a plotter. A recording apparatus may be a handy printer that is held and moved by a user's hand as a whole and relatively moves with respect to a recording medium. A recording apparatus may be one that relatively moves a recording medium and a head by moving a head by a robot or the like.

[0157] A recording medium is not limited to paper. For example, a recording medium may be cloth, wood, tile, a printed wiring board (more specifically, an insulating layer on which a conductive pattern is printed), or a vehicle body.

[0158] A head may be used for applications other than a recording apparatus. For example, a head may be used for manufacturing chemical agents. Specifically, for example, a head may eject a predetermined amount of a liquid chemical agent or a liquid containing a chemical agent toward a reaction vessel or the like.

[0159] As understood from examples of the above recording medium and the like, liquid is not limited to ink. For example, it may be paint, or may be a conductive material printed on a printed wiring board.

[0160] A pressurizing unit configured to apply pressure to a flow path (liquid) to eject liquid is not limited to a piezoelectric type. For example, a pressurizing unit may be one that heats liquid to generate bubbles and thereby applies pressure to liquid (a thermal type pressurizing unit).

[0161] A flow path member is not limited to one configured by laminating plates made of metal or resin. For example, it may be configured by MEMS (Micro Electro Mechanical Systems). MEMS may include not only a flow path member but also a pressurizing unit.

[0162] The following concepts can be extracted from the present disclosure.

(Concept 1)

[0163] A liquid ejection head comprising:

a first flow path including an ejection hole configured

to eject liquid, a pressurization chamber communicating with the ejection hole, and at least a portion on the pressurization chamber side of a supply path configured to supply the liquid to the pressurization chamber; and

an actuator configured to apply pressure to the pressurization chamber,

wherein an upper limit of an ejection velocity at which the liquid is ejected as one droplet without being divided into satellite droplets for each pulse width in response to a rectangular pulse configured to perform ejection by pull ejection being applied to the actuator is referred to as a single-droplet upper limit velocity, and

half of a natural vibration period of the liquid in the first flow path is referred to as AL,

the liquid ejection head satisfying at least one of the following conditions A to D, which are conditions relating to a minimum value of the single-droplet upper limit velocity in response to the pulse width being within a range of $AL \pm 25\%$:

- Condition A: The minimum value is 4.0 m/s or more.
- Condition B: The liquid ejection head further comprises a driver configured to input a first signal having a pulse height set to a predetermined operating voltage to the actuator, and the minimum value is 40.5% or more of an ejection velocity in response to the pulse having the same pulse width as a pulse width in response to the minimum value being obtained and the same pulse height as the operating voltage being applied to the actuator.
- Condition C: A ratio $(v_{\max} - v_{\min})/v_{\min}$ of a difference between the minimum value $v_{\min}$ and a maximum value $v_{\max}$ of the single-droplet upper limit velocity in response to the pulse width being within the range of $AL \pm 25\%$ to the minimum value $v_{\min}$ is 0.8 or less.
- Condition D: A quantity of a droplet ejected at the minimum value is 6.5 pL or more.

(Concept 2)

[0164] The liquid ejection head according to Concept 1, wherein the pulse width at which the single-droplet upper limit velocity takes the minimum value is within the range of $AL \pm 25\%$.

(Concept 3)

[0165] The liquid ejection head according to Concept 1 or 2, wherein

the first flow path further comprises a descender extending from the pressurization chamber to the ejection hole, and

a ratio $f2/f1$ of a natural vibration frequency $f2$ of the liquid in the descender to a natural vibration frequency $f1$ of the liquid in the first flow path is 4.15 or more and 4.43 or less.

(Concept 4)

[0166] The liquid ejection head according to any one of Concepts 1 to 3, wherein

the first flow path further comprises a descender extending from the pressurization chamber to the ejection hole, and

in an amplitude spectrum of a vibration velocity of a meniscus of the liquid at the ejection hole, a ratio $B2/B1$ of a peak intensity $B2$ of natural vibration of the liquid in the descender to a peak intensity $B1$ of natural vibration of the liquid in the first flow path is 0.19 or more and 0.29 or less.

(Concept 5)

[0167] The liquid ejection head according to any one of Concepts 1 to 4, wherein

the first flow path further comprises a descender extending from the pressurization chamber to the ejection hole,

the descender comprises a changing portion in which a cross-sectional area becomes narrower or wider,

in response to

a length of the descender being $L0$,

a length of a first communication path between the pressurization chamber and the changing portion being $L1$,

a length of a second communication path between the changing portion and the ejection hole being $L2$,

a cross-sectional area of the first communication path being $S1$,

a cross-sectional area of the second communication path being $S2$,

a cross-sectional area of the changing portion being $S3$,

a combined inertance of the pressurization chamber and the first communication path being $M1$,

a combined compliance of the pressurization chamber and the first communication path being $C1$,

a combined inertance of the ejection hole and the second communication path being $M2$, and

a combined compliance of the ejection hole and the second communication path being $C2$,

$$0.16 \leq L2/L0 \leq 0.51,$$

$$0.04 \leq L3/L0 \leq 0.19,$$

$$0.23 \leq S3/S1 \leq 1.86,$$

$$0.22 \leq S3/S2 \leq 1.80,$$

$$0.22 \leq M2/M1 \leq 0.41,$$

and

$$0.15 \leq C2/C1 \leq 0.72$$

are satisfied.

(Concept 6)

[0168] A recording apparatus comprising:

the liquid ejection head according to any one of Concepts 1 to 5; and
a moving unit configured to relatively move the liquid ejection head and a recording medium facing the ejection surface along the ejection surface.

[0169] Also, from the present disclosure, unlike the above, an invention that does not require that a minimum value of a single-droplet upper limit velocity satisfies a predetermined condition may be extracted. For example, an invention that requires that $M2/M1$ is 0.26 or more and/or $C2/C1$ is 0.24 or more may be extracted.

REFERENCE SIGNS

[0170] 1... Printer (recording apparatus), 3... Head (liquid ejection head), 7... Ejection hole, 11... Pressurization chamber, 13... Supply path, 17... First flow path, 19... Actuator, 27... Head main body (liquid ejection head).

Claims

1. A liquid ejection head comprising:

a first flow path including an ejection hole configured to eject liquid, a pressurization chamber communicating with the ejection hole, and at least a portion on the pressurization chamber side of a supply path configured to supply the liquid to the pressurization chamber; and
an actuator configured to apply pressure to the pressurization chamber,
wherein an upper limit of an ejection velocity at which the liquid is ejected as one droplet without being divided into satellite droplets for each pulse width in response to a rectangular pulse configured to perform ejection by pull ejection

being applied to the actuator is referred to as a single-droplet upper limit velocity, and half of a natural vibration period of the liquid in the first flow path is referred to as AL ,
a minimum value of the single-droplet upper limit velocity in response to the pulse width being within a range of $AL \pm 25\%$ is 4.0 m/s or more.

2. A liquid ejection head comprising:

a first flow path including an ejection hole configured to eject liquid, a pressurization chamber communicating with the ejection hole, and at least a portion on the pressurization chamber side of a supply path configured to supply the liquid to the pressurization chamber;
an actuator configured to apply pressure to the pressurization chamber; and
a driver configured to input a first signal having a pulse height set to a predetermined operating voltage to the actuator,
wherein an upper limit of an ejection velocity at which the liquid is ejected as one droplet without being divided into satellite droplets for each pulse width in response to a rectangular pulse configured to perform ejection by pull ejection being applied to the actuator is referred to as a single-droplet upper limit velocity, and half of a natural vibration period of the liquid in the first flow path is referred to as AL ,
a minimum value of the single-droplet upper limit velocity in response to the pulse width being within a range of $AL \pm 25\%$ is 40.5% or more of an ejection velocity in response to the pulse having the same pulse width as a pulse width in response to the minimum value being obtained and the same pulse height as the operating voltage being applied to the actuator.

3. A liquid ejection head comprising:

a first flow path including an ejection hole configured to eject liquid, a pressurization chamber communicating with the ejection hole, and at least a portion on the pressurization chamber side of a supply path configured to supply the liquid to the pressurization chamber; and
an actuator configured to apply pressure to the pressurization chamber,
wherein an upper limit of an ejection velocity at which the liquid is ejected as one droplet without being divided into satellite droplets for each pulse width in response to a rectangular pulse configured to perform ejection by pull ejection being applied to the actuator is referred to as a single-droplet upper limit velocity, and half of a natural vibration period of the liquid in the first flow path is referred to as AL ,

a ratio $(v_{\max} - v_{\min})/v_{\min}$ of a difference between a minimum value $v_{\min}$ and a maximum value $v_{\max}$ of the single-droplet upper limit velocity in response to the pulse width being within a range of $AL \pm 25\%$ to the minimum value $v_{\min}$ is 0.8 or less.

4. A liquid ejection head comprising:

a first flow path including an ejection hole configured to eject liquid, a pressurization chamber communicating with the ejection hole, and at least a portion on the pressurization chamber side of a supply path configured to supply the liquid to the pressurization chamber; and an actuator configured to apply pressure to the pressurization chamber, wherein an upper limit of an ejection velocity at which the liquid is ejected as one droplet without being divided into satellite droplets for each pulse width in response to a rectangular pulse configured to perform ejection by pull ejection being applied to the actuator is referred to as a single-droplet upper limit velocity, and half of a natural vibration period of the liquid in the first flow path is referred to as AL, a quantity of a droplet ejected at a minimum value of the single-droplet upper limit velocity in response to the pulse width being within a range of $AL \pm 25\%$ is 6.5 pL or more.

5. The liquid ejection head according to any one of claims 1 to 4, wherein the pulse width at which the single-droplet upper limit velocity takes the minimum value is within the range of $AL \pm 25\%$.

6. The liquid ejection head according to any one of claims 1 to 5, wherein

the first flow path further comprises a descender extending from the pressurization chamber to the ejection hole, and a ratio f_2/f_1 of a natural vibration frequency f_2 of the liquid in the descender to a natural vibration frequency f_1 of the liquid in the first flow path is 4.15 or more and 4.43 or less.

7. The liquid ejection head according to any one of claims 1 to 6, wherein

the first flow path further comprises a descender extending from the pressurization chamber to the ejection hole, and in an amplitude spectrum of a vibration velocity of a meniscus of the liquid at the ejection hole, a ratio B_2/B_1 of a peak intensity B_2 of natural vibration of the liquid in the descender to a peak intensity B_1 of natural vibration of the liquid in the

first flow path is 0.19 or more and 0.29 or less.

8. The liquid ejection head according to any one of claims 1 to 7, wherein

the first flow path further comprises a descender extending from the pressurization chamber to the ejection hole, the descender comprises a changing portion in which a cross-sectional area becomes narrower or wider, in response to a length of the descender being L_0 , a length of a first communication path between the pressurization chamber and the changing portion being L_1 , a length of a second communication path between the changing portion and the ejection hole being L_2 , a cross-sectional area of the first communication path being S_1 , a cross-sectional area of the second communication path being S_2 , a cross-sectional area of the changing portion being S_3 , a combined inertance of the pressurization chamber and the first communication path being M_1 , a combined compliance of the pressurization chamber and the first communication path being C_1 , a combined inertance of the ejection hole and the second communication path being M_2 , and a combined compliance of the ejection hole and the second communication path being C_2 ,

$$0.16 \leq L_2/L_0 \leq 0.51,$$

$$0.04 \leq L_3/L_0 \leq 0.19,$$

$$0.23 \leq S_3/S_1 \leq 1.86,$$

$$0.22 \leq S_3/S_2 \leq 1.80,$$

$$0.22 \leq M_2/M_1 \leq 0.41,$$

and

$$0.15 \leq C_2/C_1 \leq 0.72$$

are satisfied.

9. A recording apparatus comprising:

the liquid ejection head according to any one of claims 1 to 8; and

a moving unit configured to relatively move the liquid ejection head and a recording medium.

10. An evaluation method for a liquid ejection head comprising a first flow path including an ejection hole configured to eject liquid, a pressurization chamber communicating with the ejection hole, and at least a portion on the pressurization chamber side of a supply path configured to supply the liquid to the pressurization chamber, and an actuator configured to apply pressure to the pressurization chamber,

wherein an upper limit of an ejection velocity at which the liquid is ejected as one droplet without being divided into satellite droplets for each pulse width in response to a rectangular pulse configured to perform ejection by pull ejection being applied to the actuator is referred to as a single-droplet upper limit velocity, and half of a natural vibration period of the liquid in the first flow path is referred to as AL, the evaluation method comprising a determination of whether or not a minimum value of the single-droplet upper limit velocity in response to the pulse width being within a range of $AL \pm 25\%$ satisfies a predetermined condition.

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FIG.1

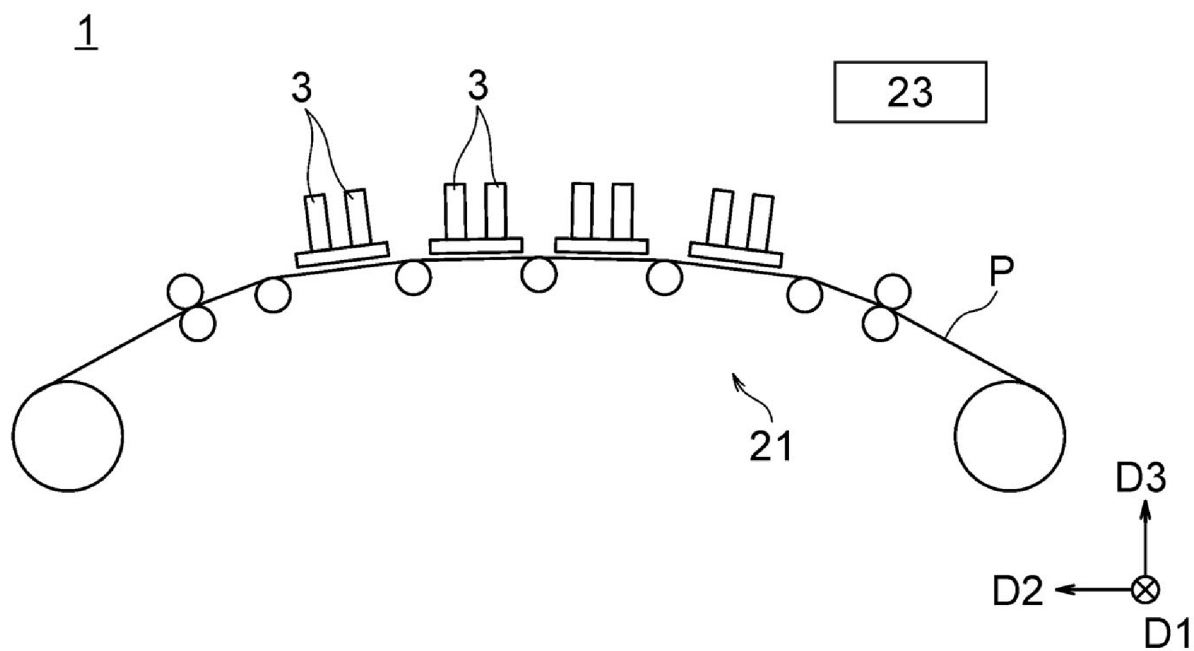


FIG.2

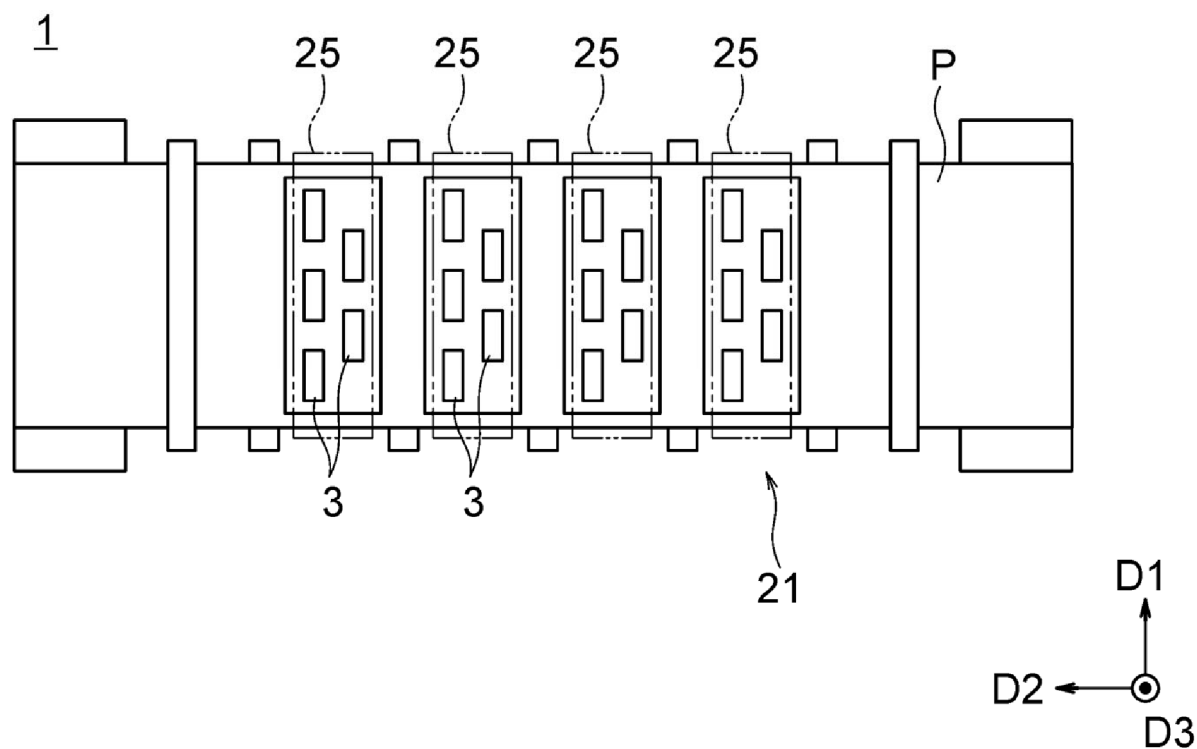


FIG.3

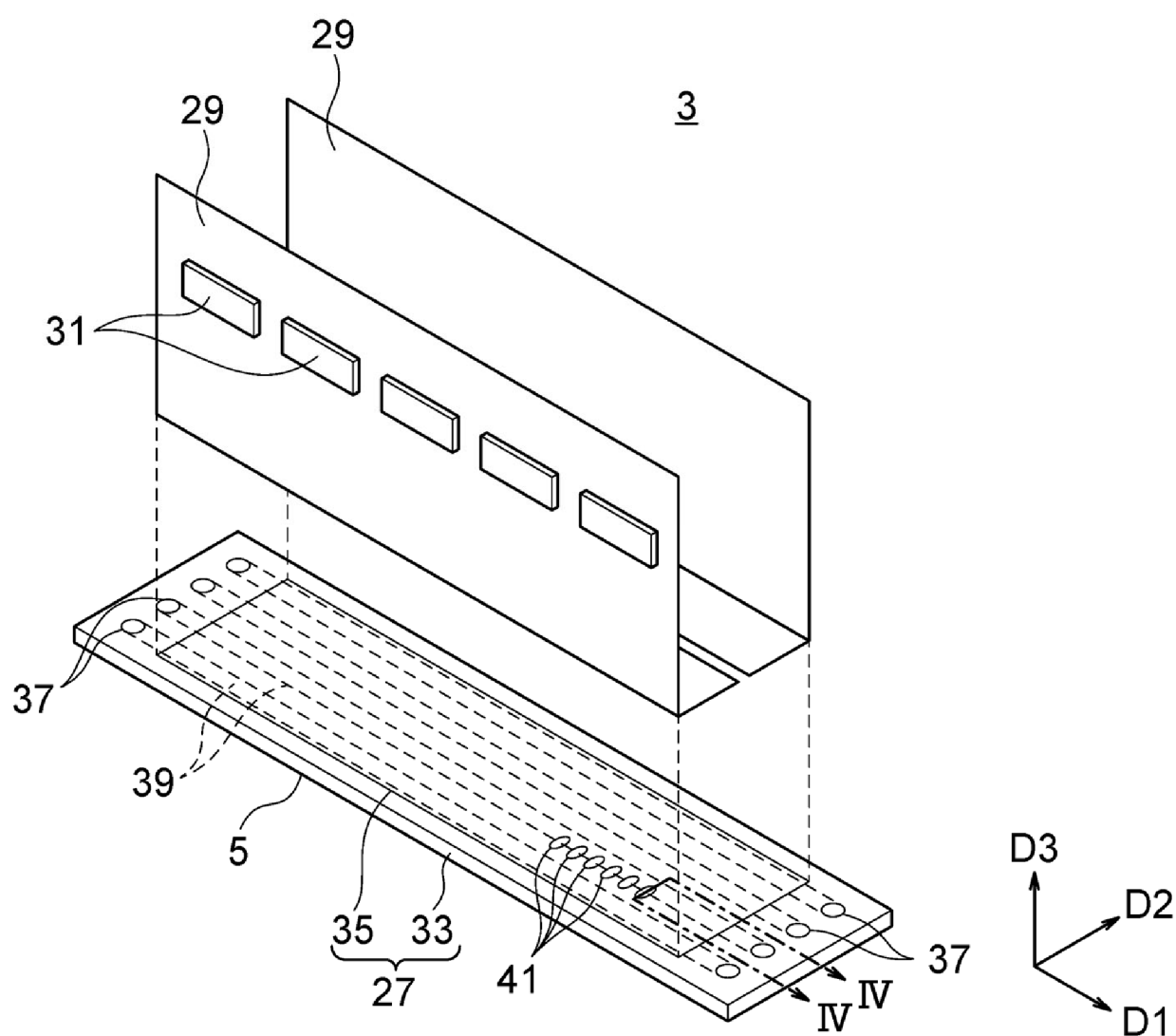


FIG.4

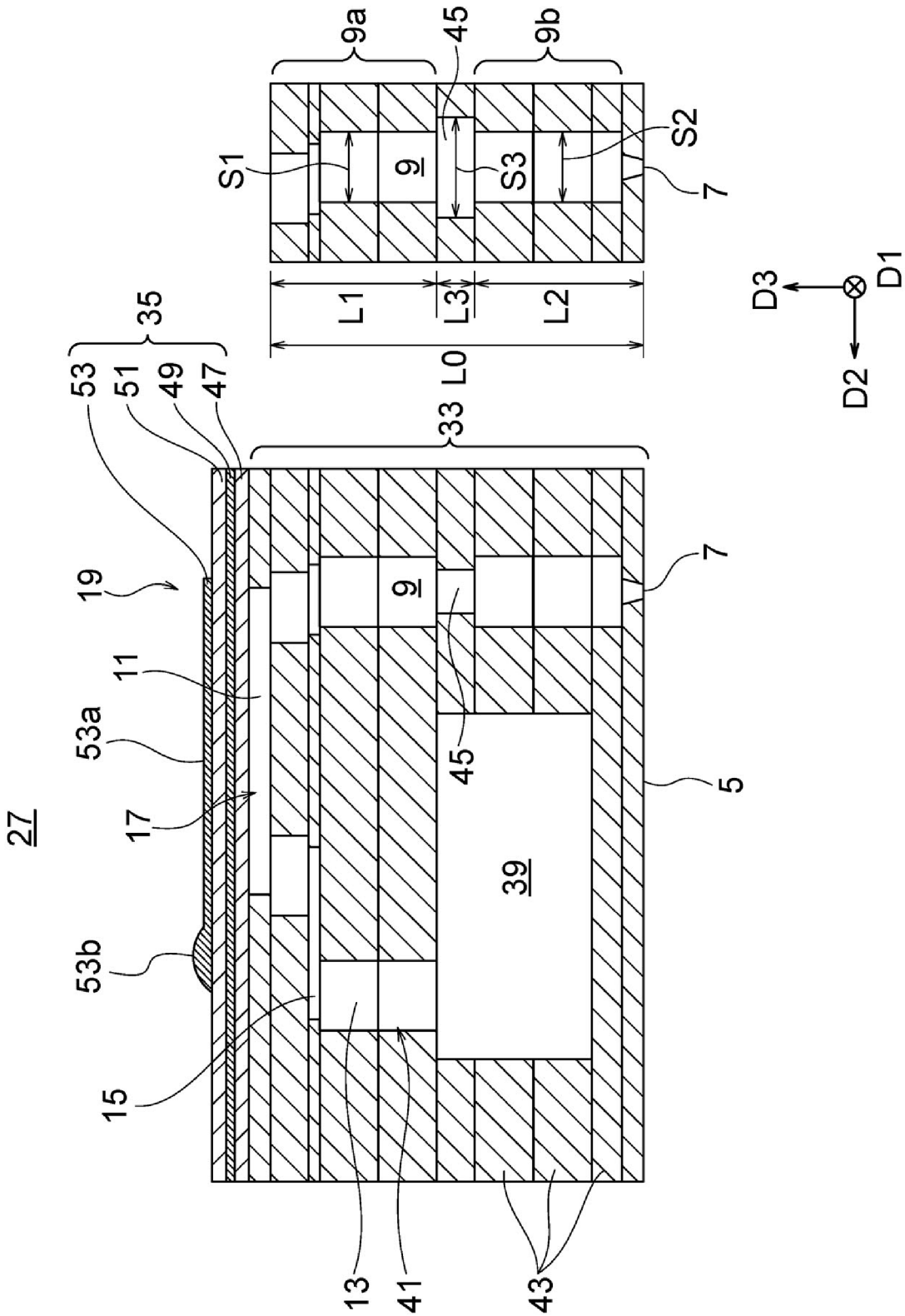


FIG.5

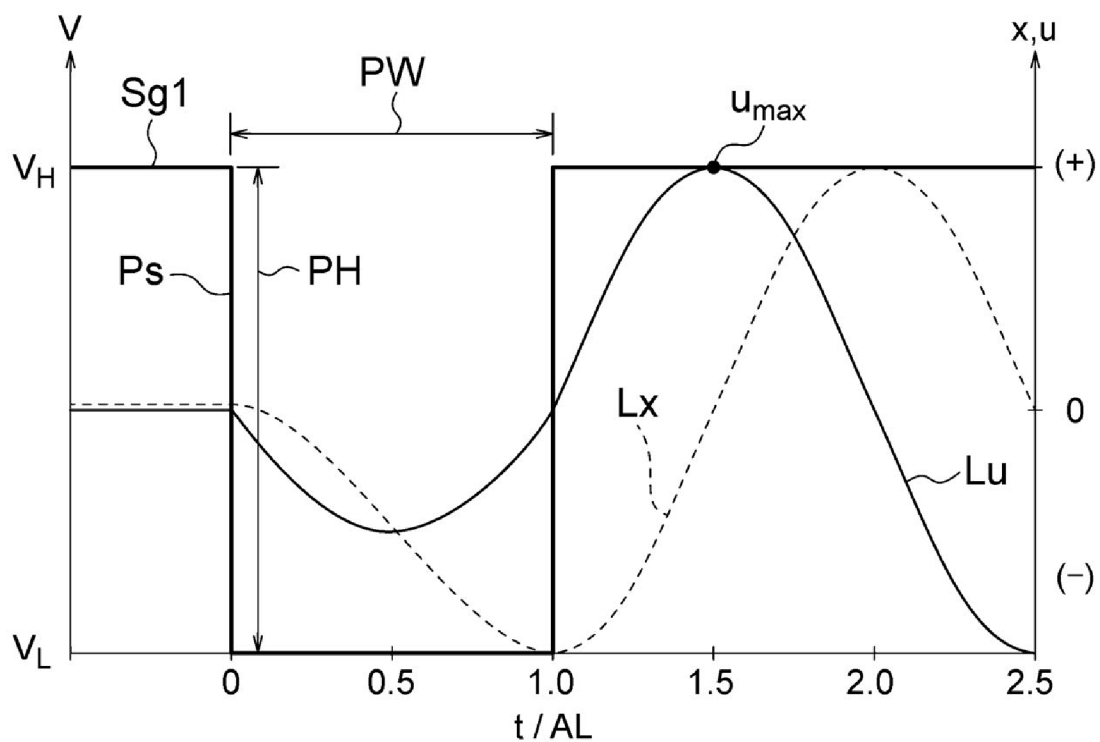


FIG.6

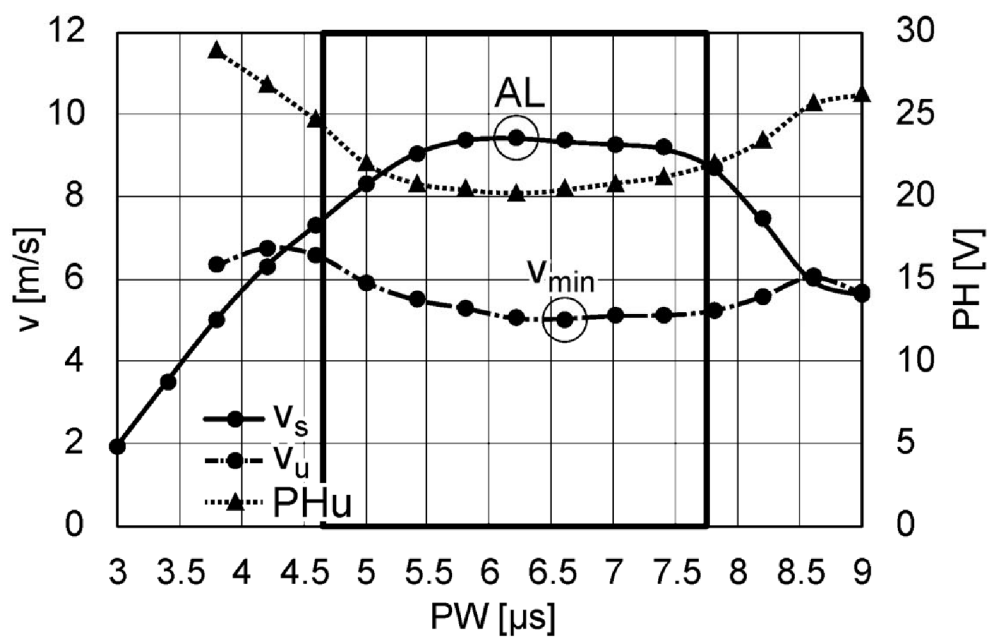


FIG.7

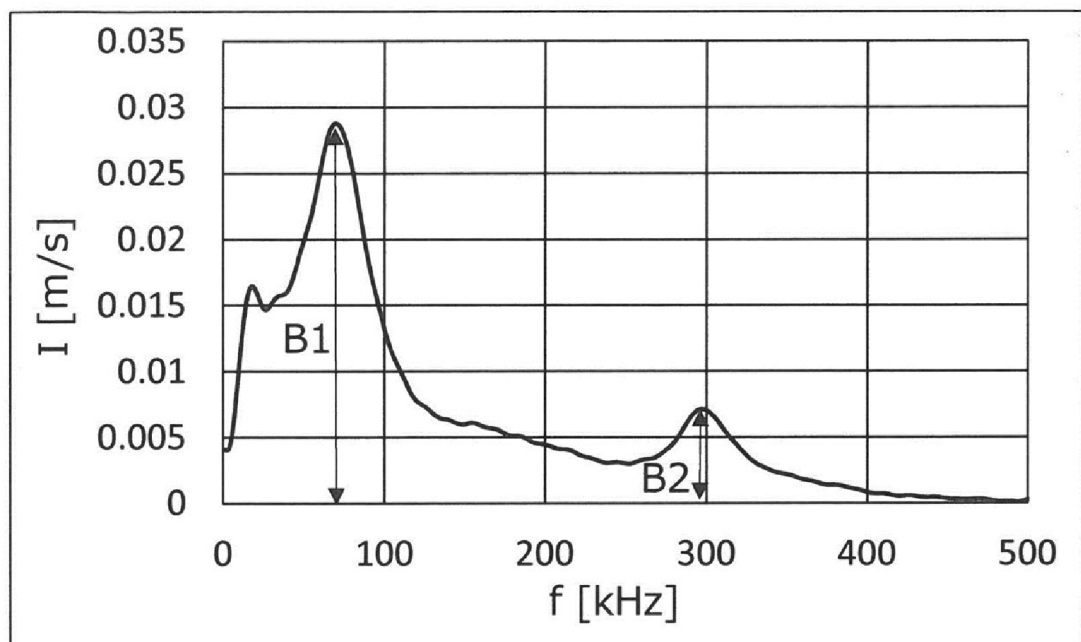


FIG.8

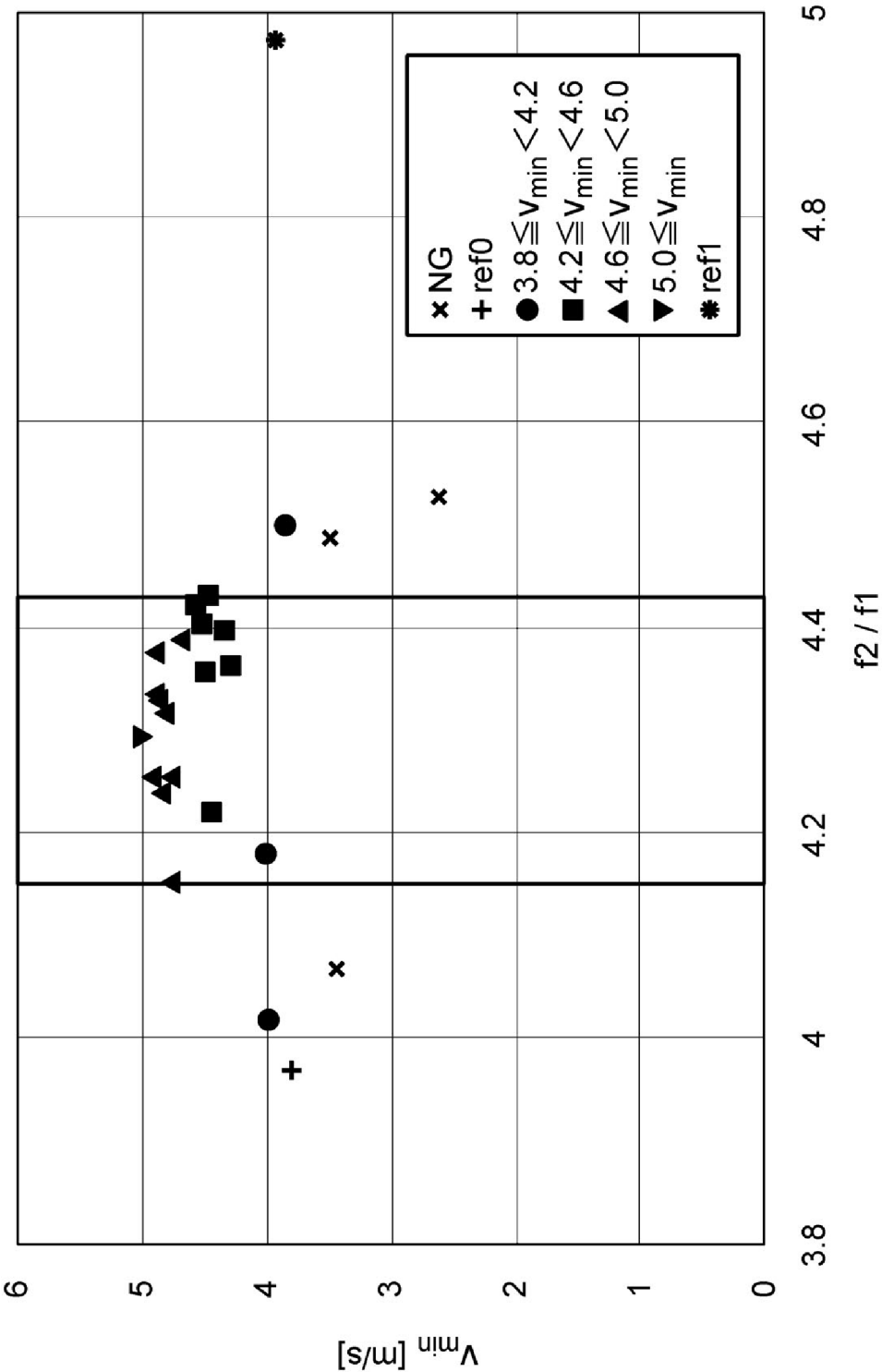


FIG.9

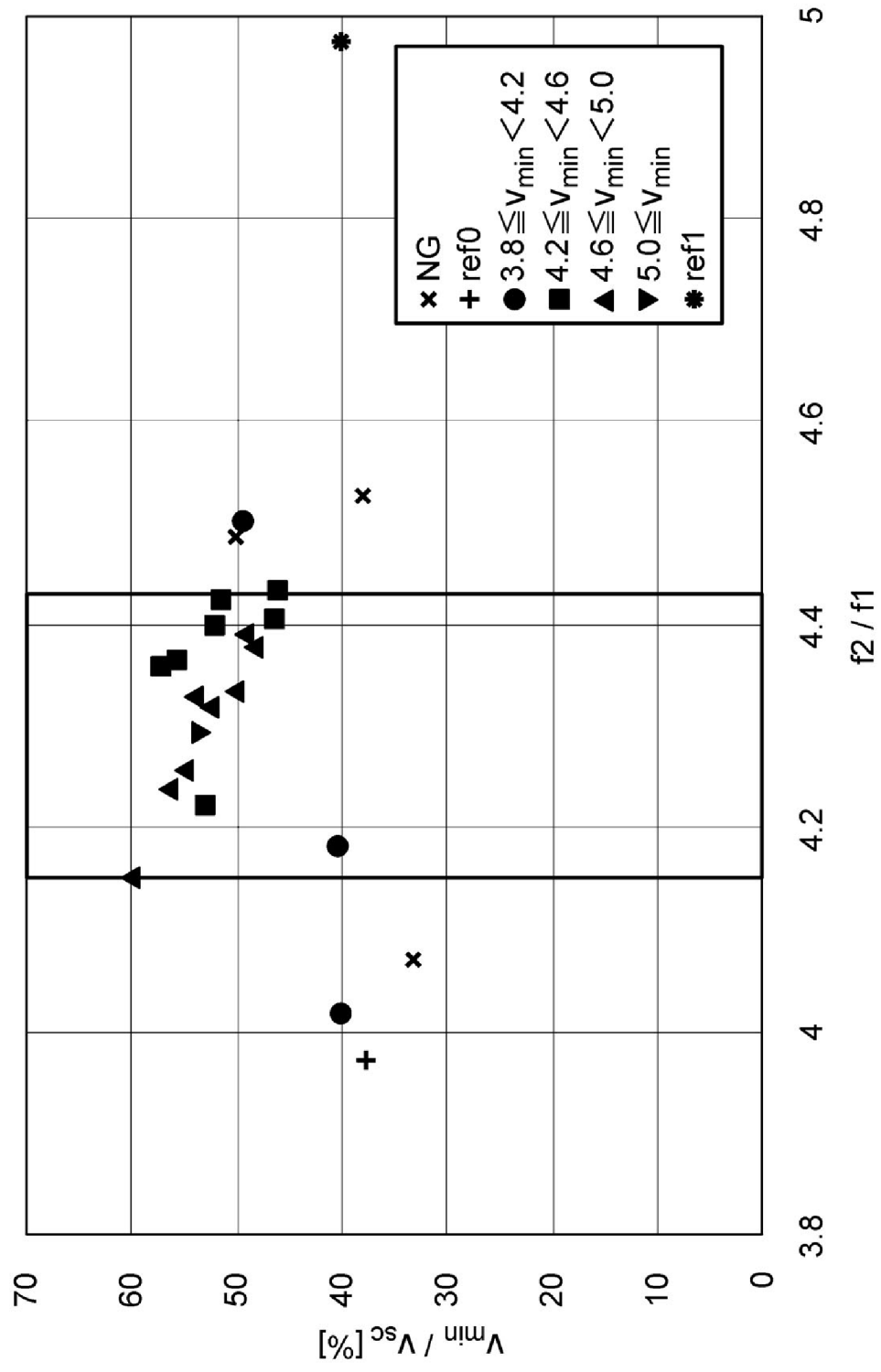


FIG.10

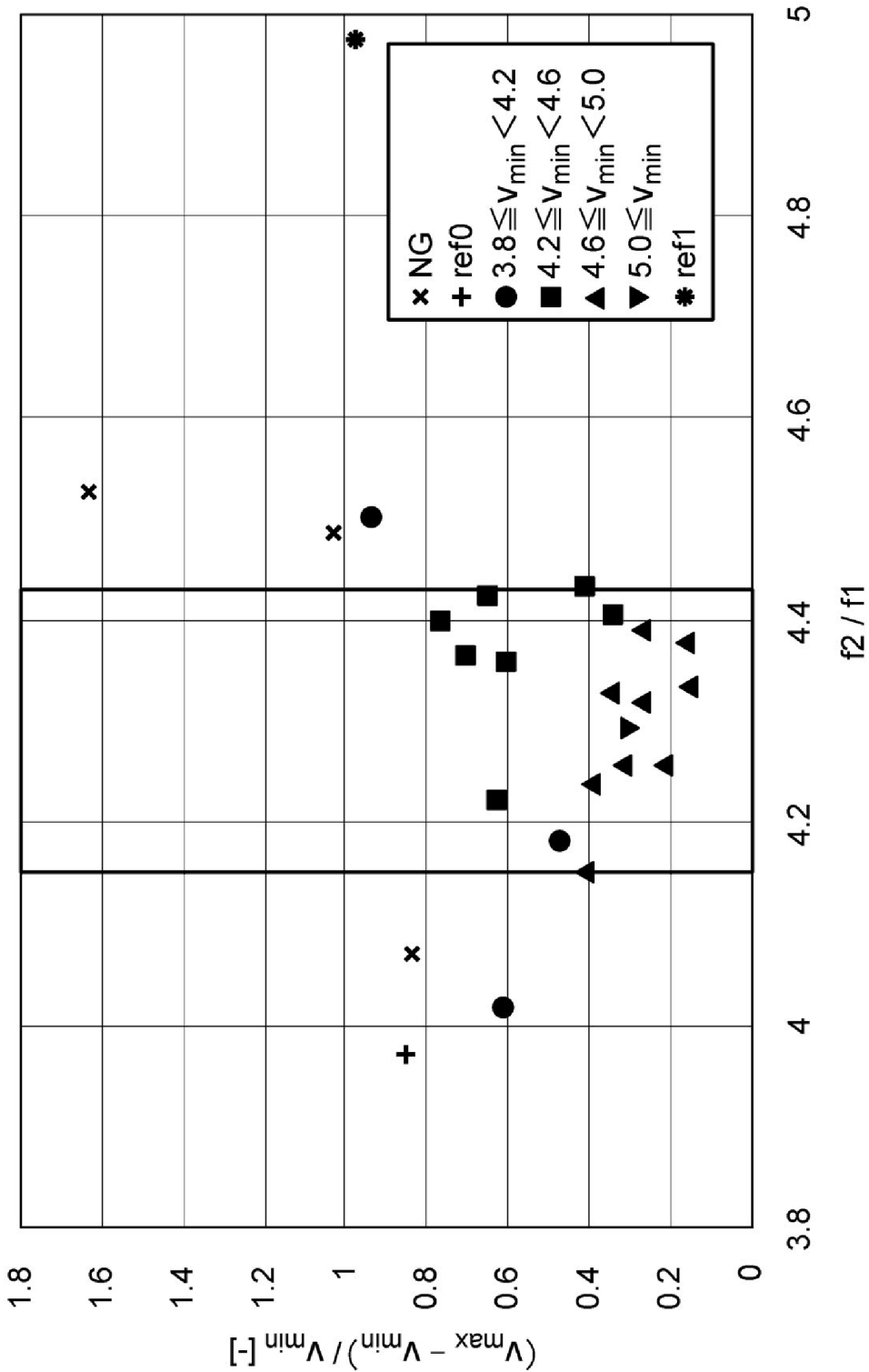


FIG.11

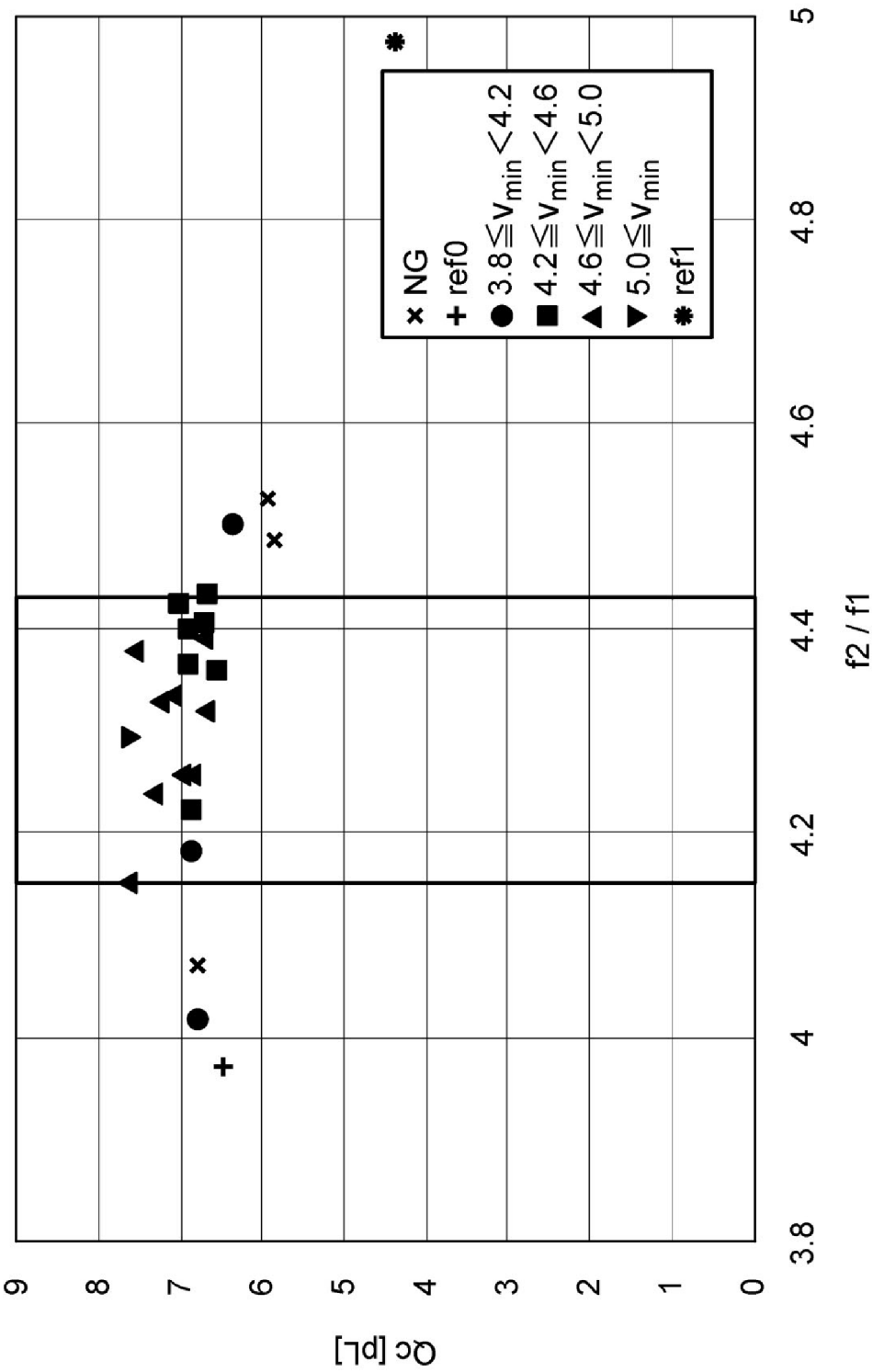


FIG.12

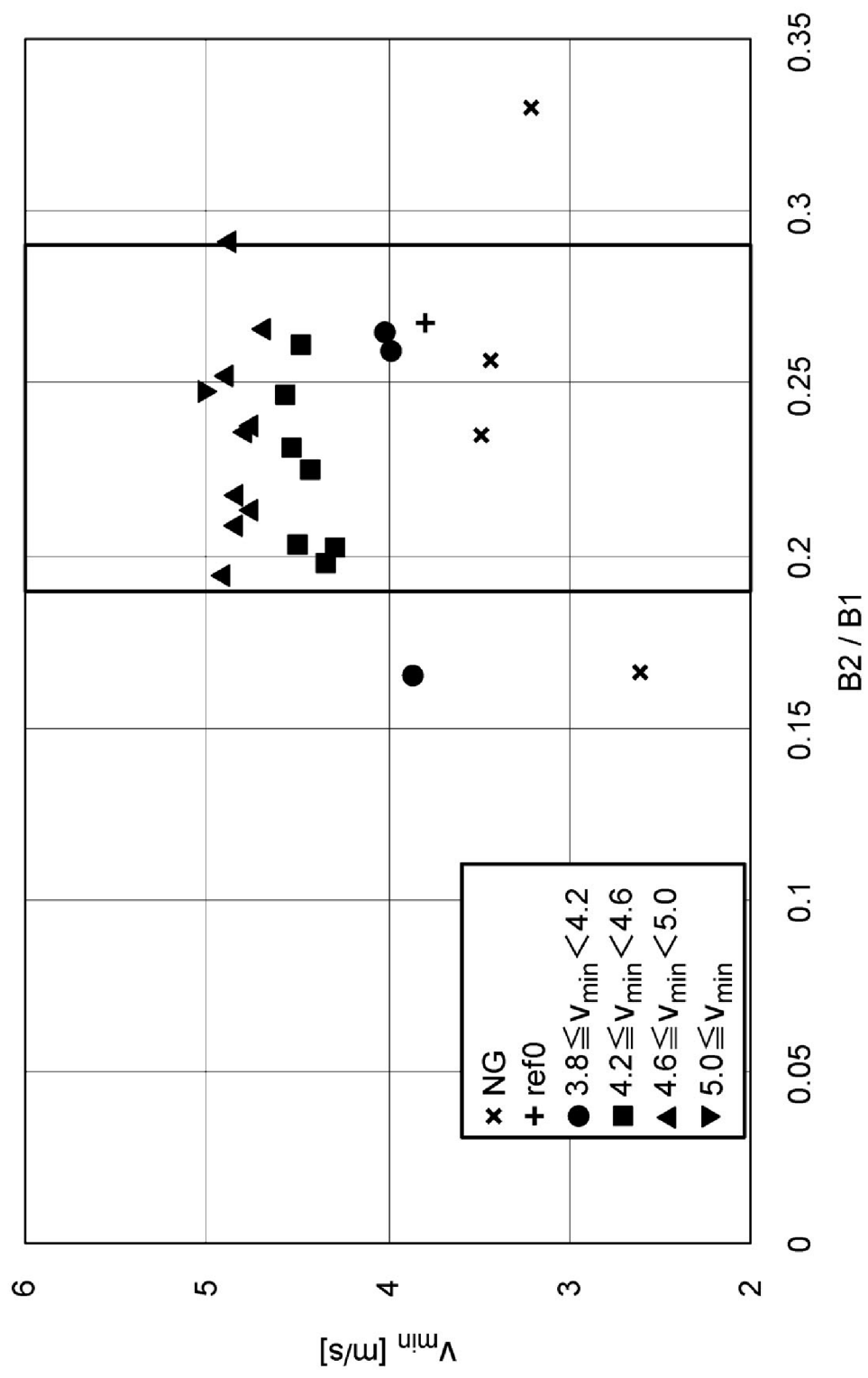


FIG.13

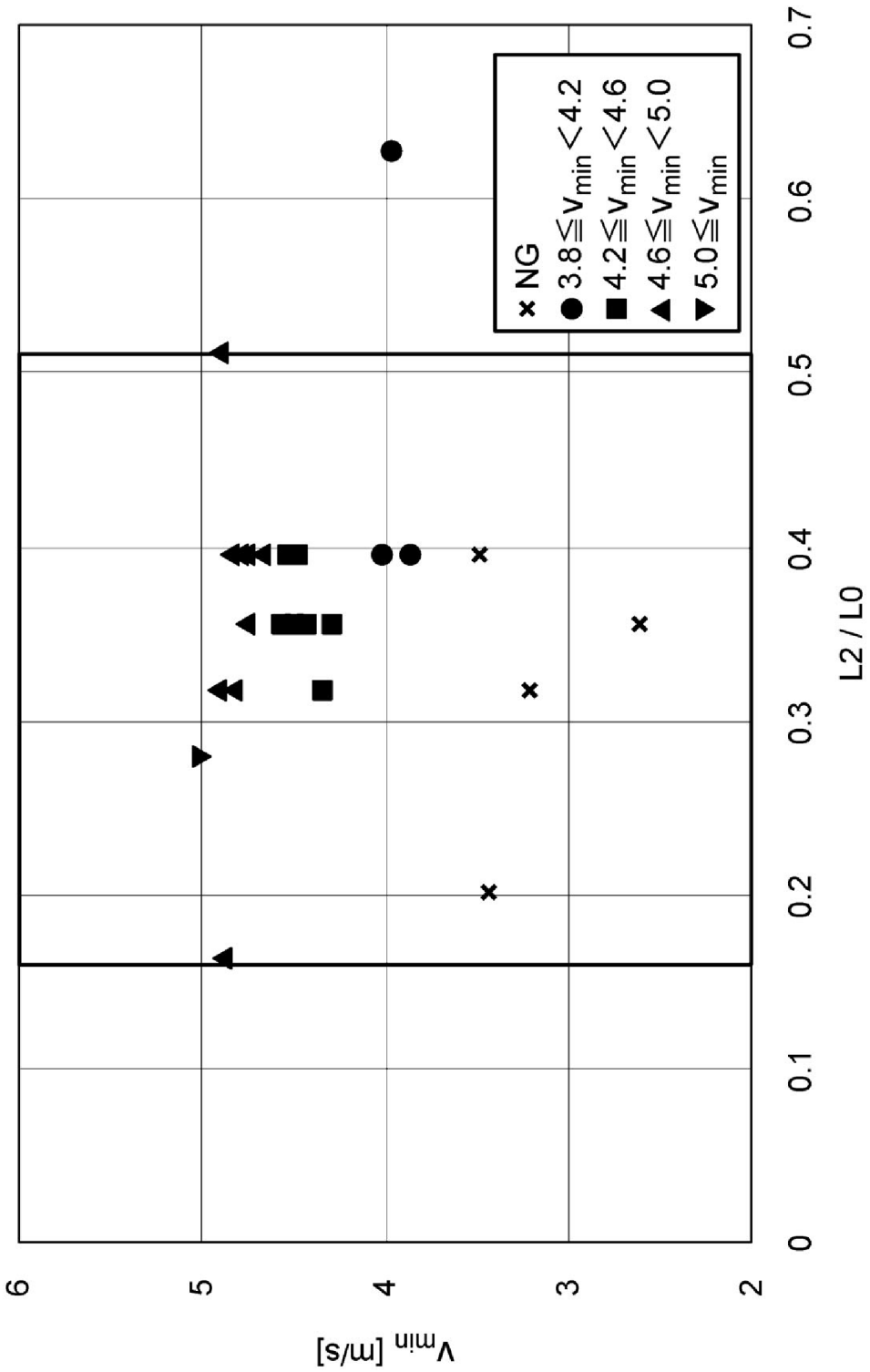


FIG.14

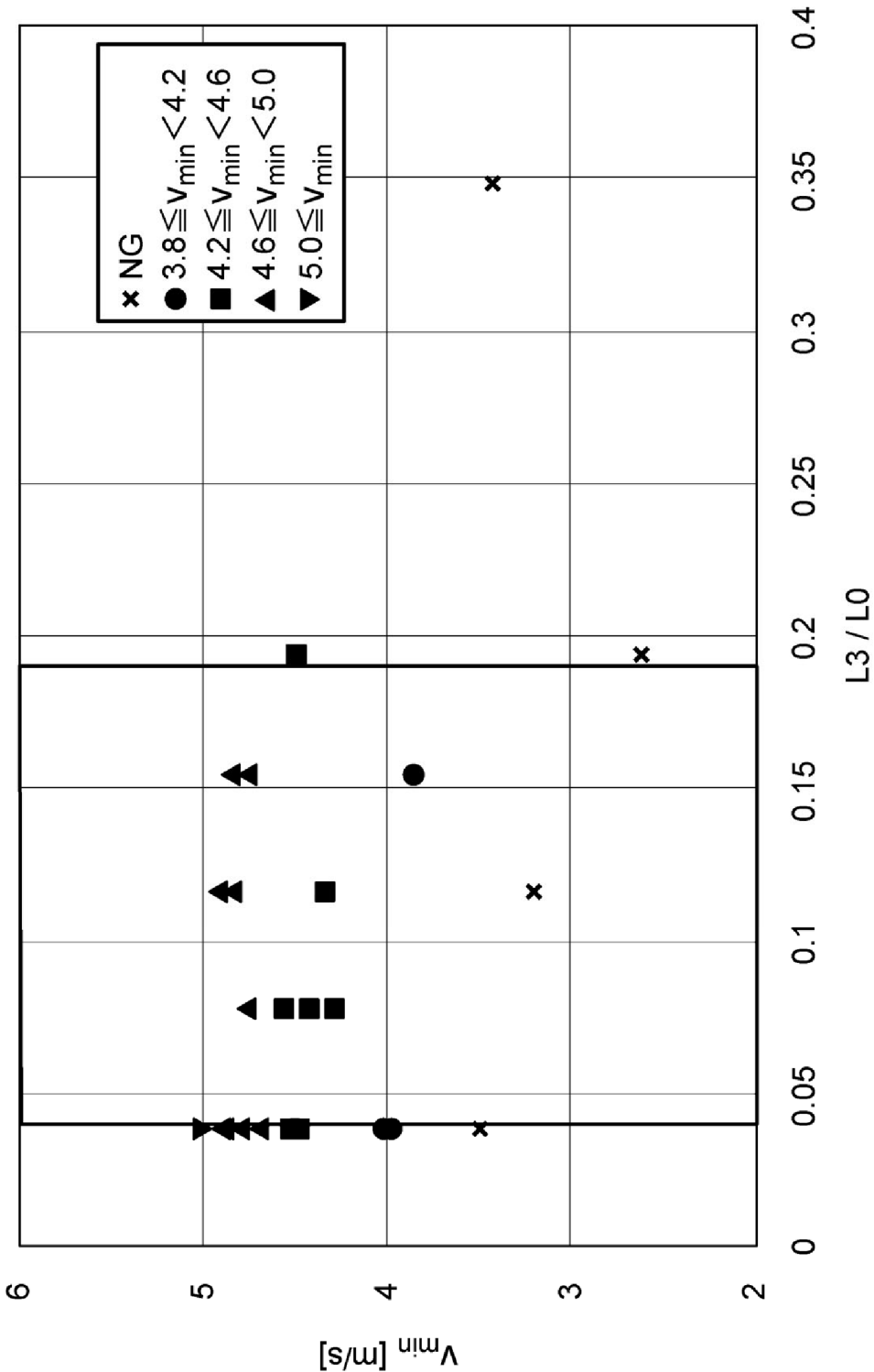


FIG.15

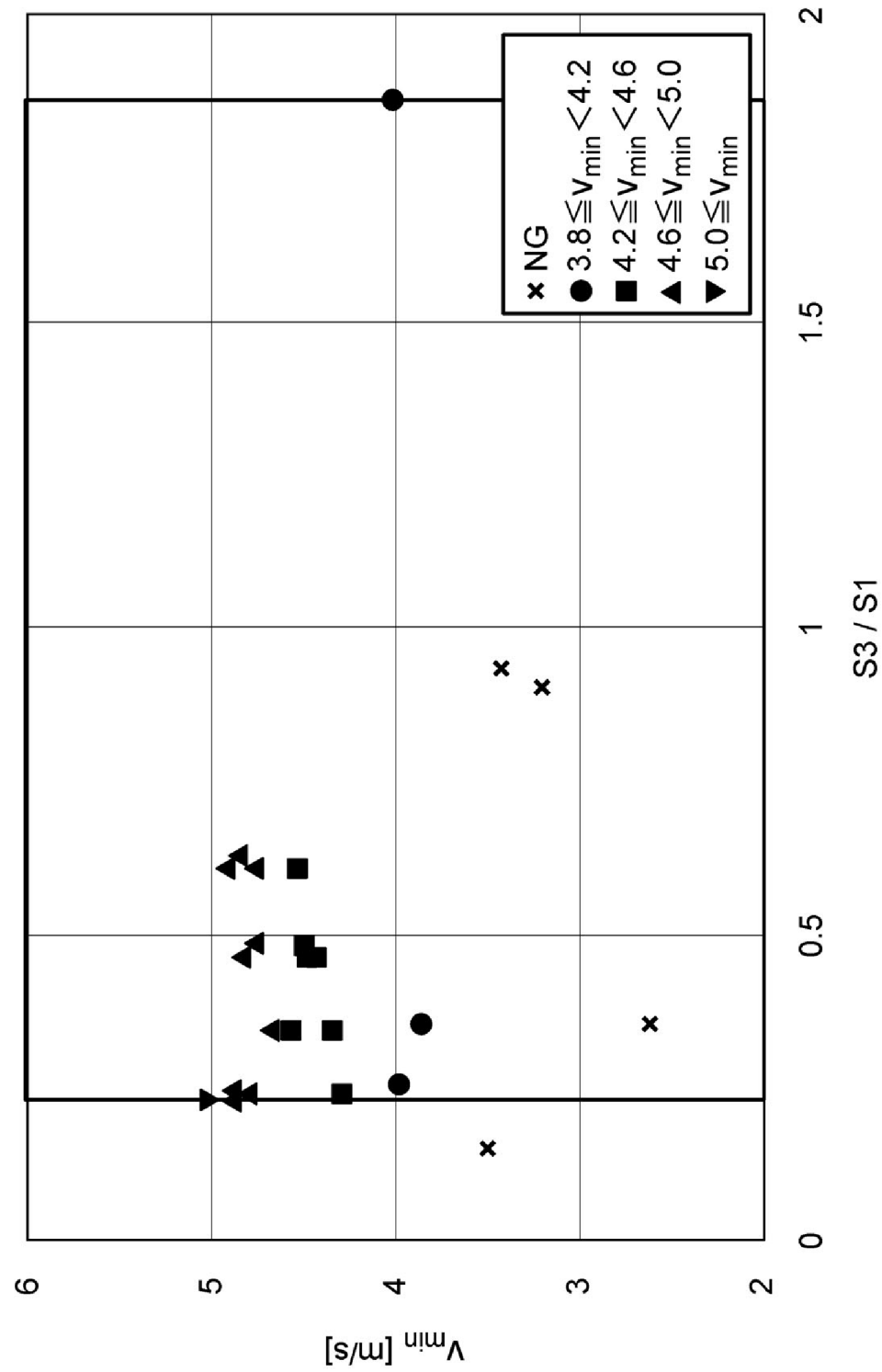


FIG.16

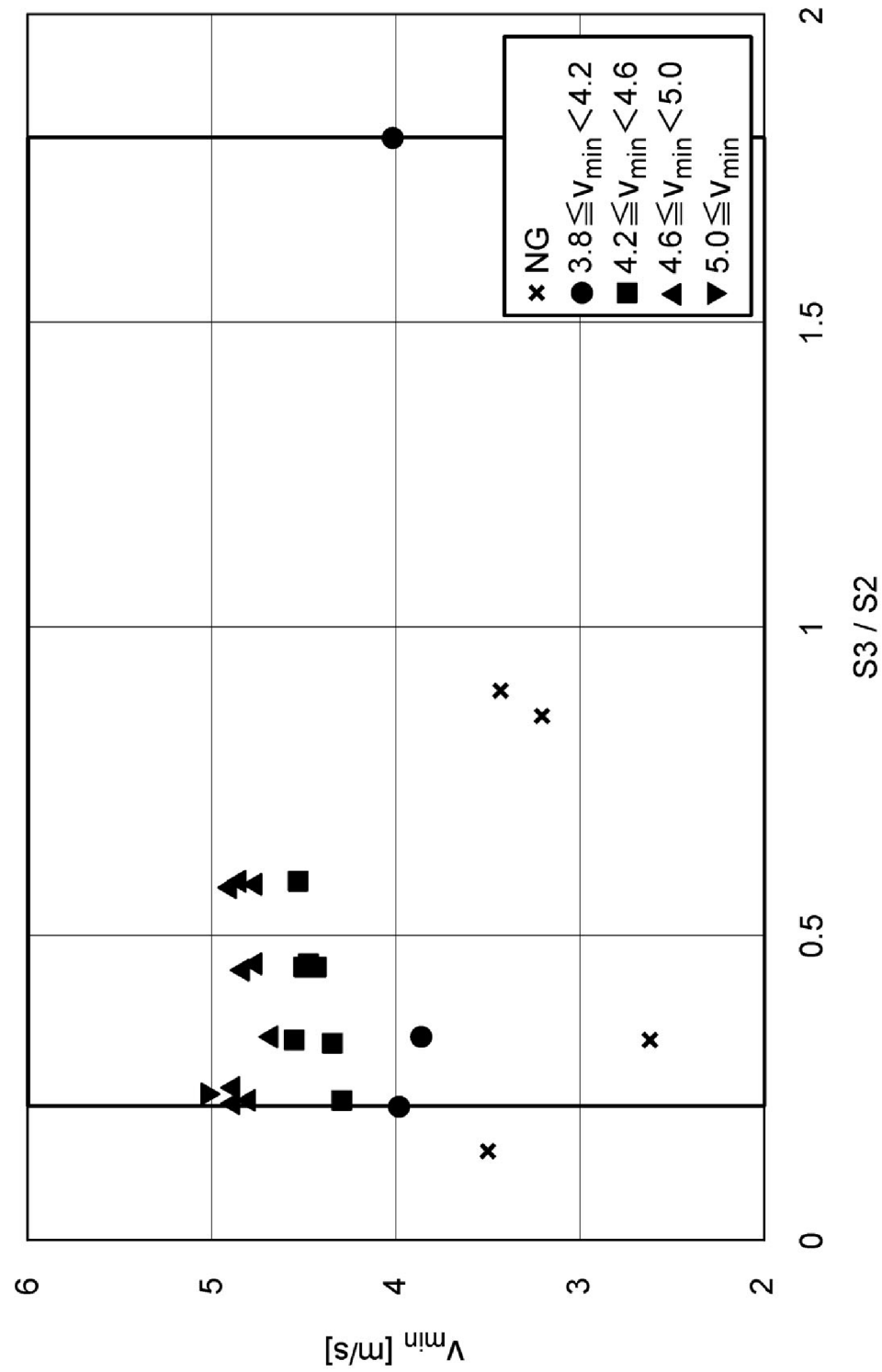


FIG. 17

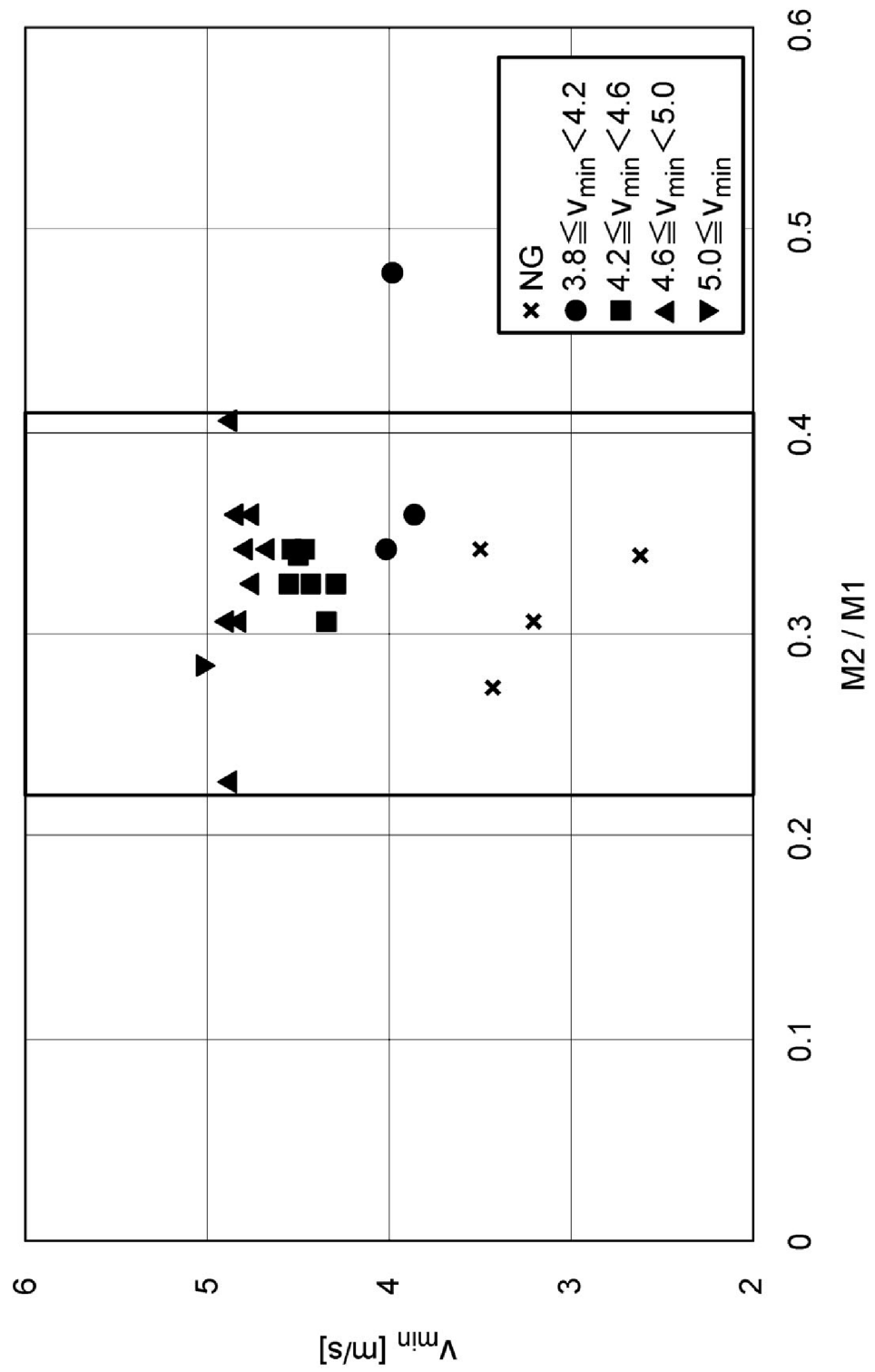


FIG.18

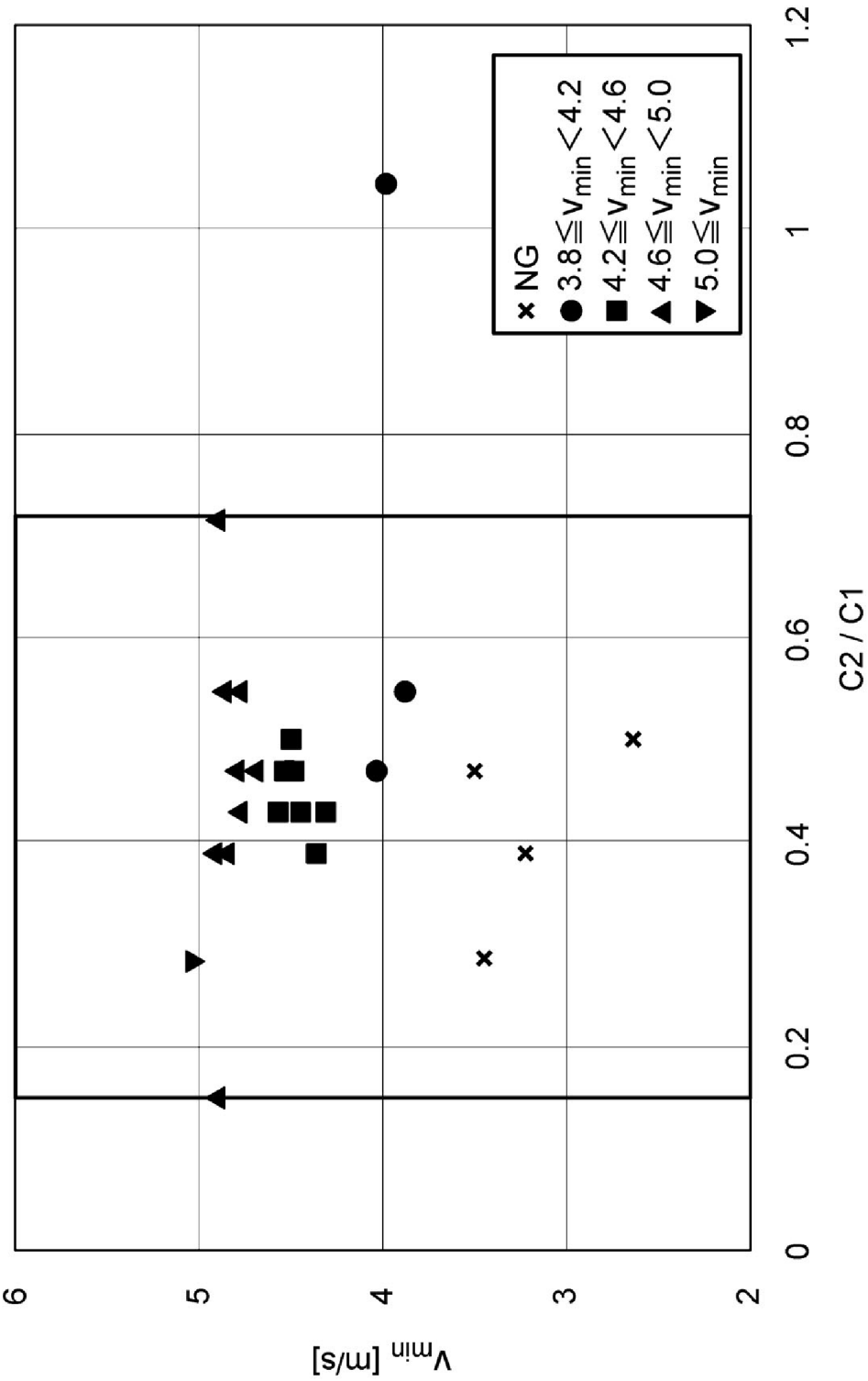
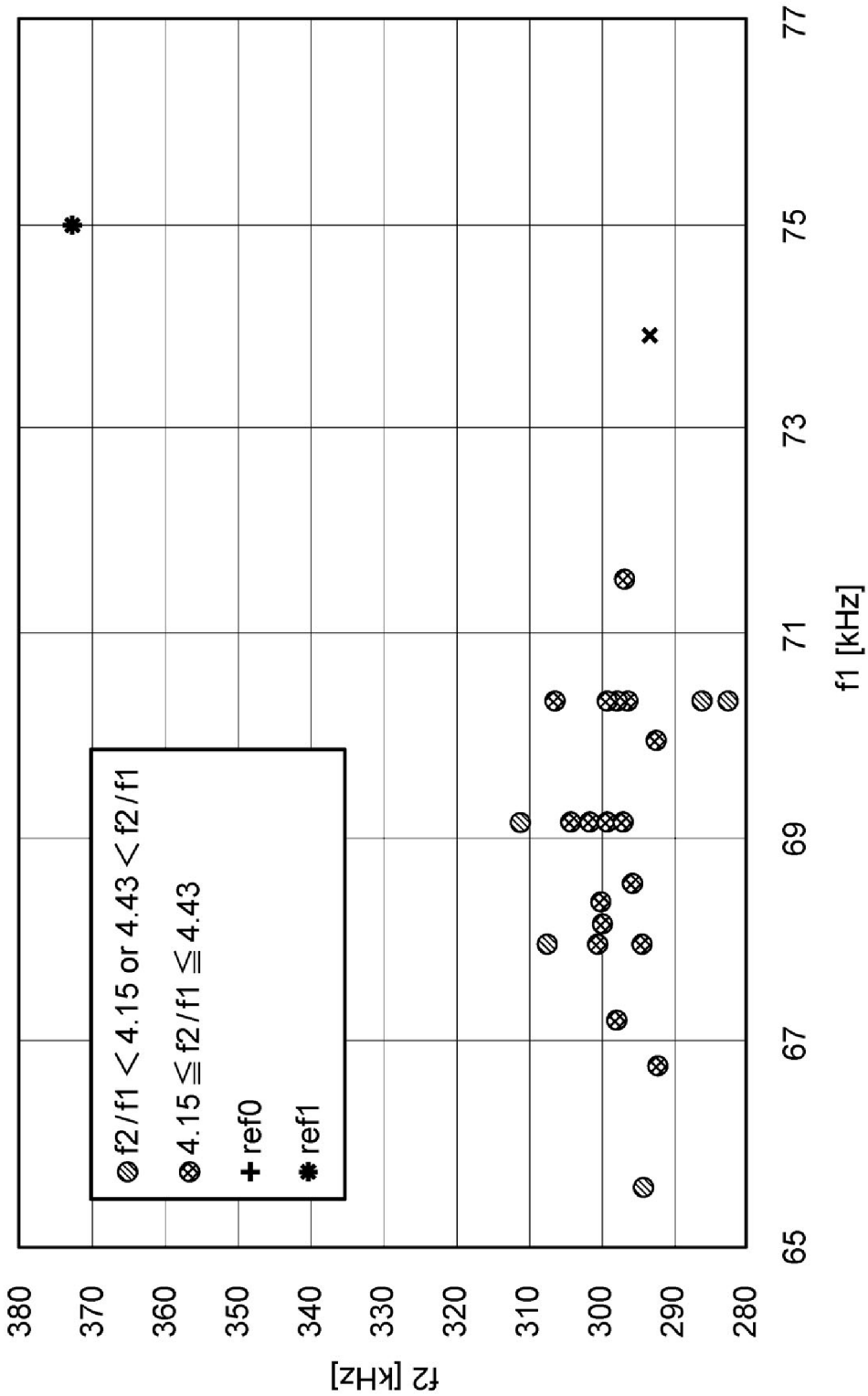


FIG.19



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2024/041912

A. CLASSIFICATION OF SUBJECT MATTER

B41J 2/015(2006.01)i; **B41J 2/14**(2006.01)i; **B41J 2/045**(2006.01)i
 FI: B41J2/015 101; B41J2/045; B41J2/14 607

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B41J2/015; B41J2/14; B41J2/045

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

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2025
 Registered utility model specifications of Japan 1996-2025
 Published registered utility model applications of Japan 1994-2025

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2010/137435 A1 (KYOCERA CORPORATION) 02 December 2010 (2010-12-02) paragraphs [0041], [0057]-[0066], fig. 5-6	1-10
A	JP 2013-248750 A (SEIKO EPSON CORPORATION) 12 December 2013 (2013-12-12) paragraphs [0028]-[0046], fig. 1-15	1-10
A	US 2022/0016884 A1 (CANON PRODUCTION PRINTING HOLDING B.V.) 20 January 2022 (2022-01-20) entire text, all drawings	1-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

27 January 2025

Date of mailing of the international search report

04 February 2025

Name and mailing address of the ISA/JP

**Japan Patent Office (ISA/JP)
 3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915
 Japan**

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2024/041912

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Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO	2010/137435	A1	02 December 2010	US 2012/0069104 A1 paragraphs [0046], [0062]-[0071], fig. 5-6	
				EP 2436520 A1	
				CN 102448727 A	
JP	2013-248750	A	12 December 2013	(Family: none)	
US	2022/0016884	A1	20 January 2022	EP 3943307 A1	

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2010137435 A [0004]