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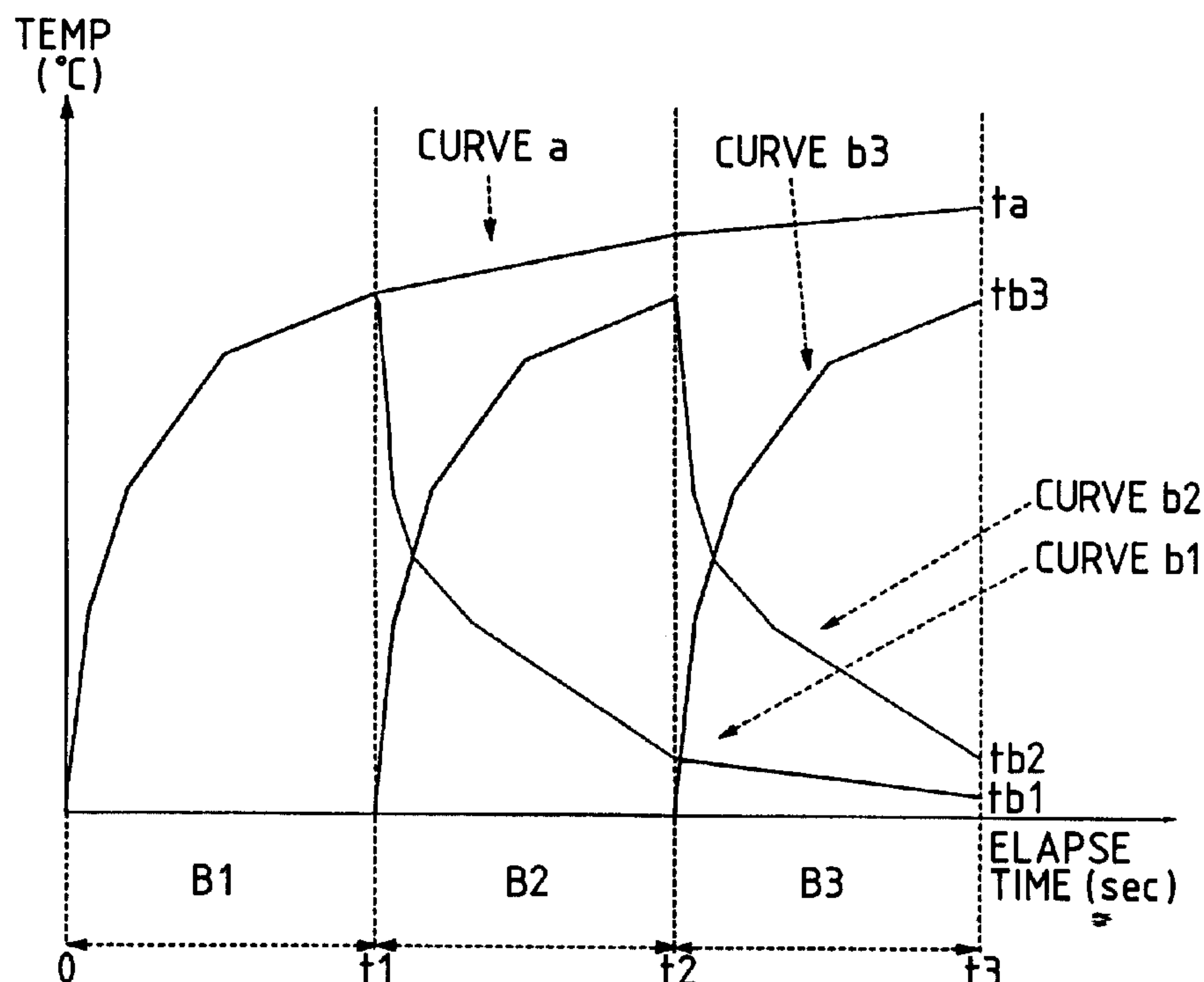
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(54) Titre : APPAREIL D'ENREGISTREMENT A JET D'ENCRE A FONCTION DE CONTROLE DE LA TEMPERATURE
(54) Title: INK JET RECORDING APPARATUS HAVING TEMPERATURE CONTROL FUNCTION



(57) Abrégé/Abstract:

An ink jet recording apparatus includes a recording head for ejecting an ink from an ejection unit to cause a change in temperature in a recording period, a temperature keeping unit for maintaining a temperature of the recording head at a predetermined keeping temperature higher than an upper limit of a surrounding temperature range in which recording is possible, a temperature prediction unit for predicting an ink temperature in the ejection unit in the recording period prior to recording, and an ejection stabilization unit for stabilizing ink ejection from the ejection unit according to the ink temperature in the ejection unit predicted by the temperature prediction unit.



1 ABSTRACT OF THE DISCLOSURE:

An ink jet recording apparatus includes a recording head for ejecting an ink from an ejection unit to cause a change in temperature in a recording period, a temperature keeping unit for maintaining a temperature of the recording head at a predetermined keeping temperature higher than an upper limit of a surrounding temperature range in which recording is possible, a temperature prediction unit for predicting an ink temperature in the ejection unit in the recording period prior to recording, and an ejection stabilization unit for stabilizing ink ejection from the ejection unit according to the ink temperature in the ejection unit predicted by the temperature prediction unit.

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1 Ink Jet Recording Apparatus Having
 Temperature Control Function

BACKGROUND OF THE INVENTION

5 Field of the Invention

 The present invention relates to an ink jet
recording apparatus for stably performing recording by
ejecting an ink from a recording head to a recording
medium and also to a temperature calculation method for
10 calculating a temperature drift of the recording head.

Related Background Art

 In the recent industrial fields, various products
for converting input energy into heat, and utilizing
the converted heat energy have been developed. In most
15 of such products utilizing the heat energy, the
relationship between the time and the temperature of an
object obtained based on the input energy is an
important control item.

 A recording apparatus such as a printer, a copying
20 machine, a facsimile machine, or the like records an
image consisting of dot patterns on a recording medium
such as a paper sheet, a plastic thin film, or the like
on the basis of image information. The recording
apparatuses can be classified into an ink jet type, a
25 wire dot type, a thermal type, a laser beam type, and
the like. Of these types, the ink jet type apparatus
(ink jet recording apparatus) ejects flying ink

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1 (recording liquid) droplets from ejection orifices of a
recording head, and attaches the ink droplets to a
recording medium, thus attaining recording.

In recent years, a large number of recording
5 apparatuses are used, and have requirements for
high-speed recording, high resolution, high image
quality, low noise, and the like. As a recording
apparatus which can meet such requirements, the ink jet
recording apparatus is known. In the ink jet recording
10 apparatus for performing recording by ejecting an ink
from a recording head, stabilization of ink ejection
and stabilization of an ink ejection quantity required
for meeting the requirements are considerably
influenced by the temperature of the ink in an ejection
15 unit. More specifically, when the temperature of the
ink is too low, the viscosity of the ink is abnormally
decreased, and the ink cannot be ejected with normal
ejection energy. On the contrary, when the temperature
is too high, the ejection quantity is increased, and
20 the ink overflows on a recording sheet, resulting in
degradation of image quality.

For this reason, in the conventional ink jet
recording apparatus, a temperature sensor is arranged
on a recording head unit, and a method of controlling
25 the temperature of the ink in the ejection unit on the
basis of the detection temperature of the recording
head to fall within a desired range, or a method of

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1 controlling ejection recovery processing is employed.
As the temperature control heater, a heater member
joined to the recording head unit, or ejection heaters
themselves in an ink jet recording apparatus for
5 performing recording by forming flying ink droplets by
utilizing heat energy, i.e., in an apparatus for
ejecting ink droplets by growing bubbles by film
boiling of the ink, are often used. When the ejection
heaters are used, they must be energized or powered on
10 so as not to produce bubbles.

In a recording apparatus for obtaining ejection
ink droplets by forming bubbles in a solid state ink or
liquid ink using heat energy, the ejection
characteristics vary depending on the temperature of
15 the recording head. Therefore, it is particularly
important to control the temperature of the ink in the
ejection unit and the temperature of the recording
head, which considerably influences the temperature of
the ink.

20 However, it is very difficult to measure the ink
temperature in the ejection unit, which considerably
influences the ejection characteristics as the
important factor upon temperature control of the
recording head, since the detection temperature of the
25 sensor drifts beyond the temperature drift of the ink
necessary in control because the ejection unit is also
a heat source, and since the ink itself moves. For

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1 this reason, even if the temperature sensor is merely
arranged near the recording head to measure the
temperature of the ink upon ejection with high
precision, it is rather difficult to measure the
5 temperature drift of the ink itself.

As one means for controlling the temperature of
the ink, an ink jet recording apparatus for indirectly
realizing stabilization of the ink temperature by
stabilizing the temperature of the recording head is
10 proposed. U.S. Patent No. 4,910,528 discloses an ink
jet printer, which has a means for stabilizing the
temperature of the recording head upon recording
according to the predicted successive driving amount of
ejection heaters with reference to the detection
15 temperature of the temperature sensor arranged very
close to the ejection heaters. More specifically, a
heating means of the recording head, an energization
means to the ejection heaters, a carriage drive control
means for maintaining the temperature of the recording
20 head below a predetermined value, a carriage scan delay
means, a carriage scan speed decreasing means, a change
means for a recording sequence of ink droplet ejection
from the recording head, and the like are controlled
according to the predicted temperature, thereby
25 stabilizing the temperature of the recording head.

However, the ink jet printer disclosed in U.S.
Patent No. 4,910,528 may pose a problem such as a

1 decrease in recording speed since it has priority to
stabilization of the temperature of the recording head.

On the other hand, since a temperature detection
member for the recording head, which is important upon
5 temperature control of the recording head, normally
suffers from variations, the detection temperatures
often vary in units of recording heads. Thus, a method
of calibrating or adjusting the temperature detection
member of the recording head before delivery of the
10 recording apparatus, or a method of providing a
correction value of the temperature detection member to
the recording head itself, and automatically correcting
the detection temperature when the head is attached to
the recording apparatus main body, is employed.

15 However, in the method of calibrating or adjusting
the temperature detection member before delivery of the
recording apparatus, when the recording head must be
exchanged, or contrarily, when an electrical circuit
board of the main body must be exchanged, the
20 temperature detection member must be re-calibrated or
re-adjusted, and jigs for re-calibration or
re-adjustment must be prepared. In order to provide
the correction value to the recording head itself, the
correction value must be measured in units of recording
25 heads, and a special memory means must be provided to
the recording head. In addition, the main body must
have a detection means for reading the correction

1 value, resulting in demerits in terms of cost and the
arrangement of the apparatus.

In the method of using the ejection heaters in
temperature control, two major methods are proposed.
5 One method is a method of simply using the ejection
heaters in the same manner as a temperature keeping
heater. In this method, short pulses, which do not
cause production of bubbles, are continuously applied
to the ejection heaters in a non-print state, e.g., in
10 a standby state wherein no recording operation is
performed, thereby keeping the temperature. The other
method is a method based on multi-pulse PWM (pulse
width modulation) control. In this method, in place of
keeping the temperature in the non-print state such as
15 the standby state, two pulses per ejection are applied
to each heater, so that the temperature of the ink at a
boundary portion with the heater is increased by the
first pulse, and a bubble is produced by the next
pulse, thus performing ejection. In order to change
20 the ejection quantity in this method, the pulse width
of the first pulse which is ON first is varied within a
bubble non-production range to increase the energy
quantity to be input to the heater, thereby increasing
the temperature of the ink located at an interface
25 portion with the heater.

1 However, the above-mentioned method, which is
executed for the purpose of stabilizing the ejection
quantity, has the following problems to be solved.

 In the method using the temperature keeping
5 heater, the entire head having a large heat capacity
must be kept at a predetermined temperature by the
temperature keeping heater, and extra energy therefor
must be input. In addition, the temperature rise
requires much time, and results in wait time in the
10 first print operation. Furthermore, in a portable
recording apparatus, since a battery must also be used
for keeping the temperature, the maximum print count is
undesirably decreased. When the temperature keeping
heater and ejection heaters are simultaneously turned
15 on, a large current must instantaneously flow through a
power supply, a flexible cable, and the like, thus
increasing cost and disturbing a compact structure.

 In the method using the multi-pulse PWM control,
since the pulse width of the second pulse for bubble
20 production is fixed, and that of the first pulse is
varied to vary the energy quantity to be input to the
head so as to vary the ejection quantity, energy larger
than normal must be supplied to the head in order to
obtain the maximum ejection quantity. Therefore,
25 although real-time characteristics can be remarkably
improved as compared to the method using the
temperature keeping heater, a further improvement is

1 required for instantaneous power and the load on the
battery.

It is also required to record a halftone image by
controlling the ink ejection quantity according to a
5 halftone signal. However, in the above-mentioned
ejection quantity control, the ejection quantity
variation range is not sufficient, and is required to
be further widened.

SUMMARY OF THE INVENTION

10 The present invention has been made to solve the
above-mentioned problems, and has as its object to
provide an ink jet recording apparatus, which predicts
the ink temperature in an ejection unit with high
precision, and stabilizes ejection so as to correspond
15 to the ink temperature drift.

It is another object of the present invention to
provide an ink jet recording apparatus, which does not
require special jigs upon exchange of a recording head
or an electrical circuit board, and can precisely
20 detect the temperature of the recording head without
causing complicated processes and without an increase
in cost depending on measurement of a correction value
of the recording head and addition of reading means to
an apparatus main body.

25 It is still another object of the present
invention to provide a temperature calculation method
for precisely calculating the temperature drift of an

1 object without arranging a temperature sensor to the
object.

It is still another object of the present
invention to provide a recording apparatus, which can
5 detect the temperature of the recording head without
providing a temperature sensor to the recording head,
and also to provide a recording apparatus, which can
stabilize an ejection quantity, an ejection operation,
and a recording operation.

10 It is still another object of the present
invention to provide a recording apparatus, which can
control the temperature of a recording head to fall
within a desired range even when the print ratio is
changed.

15 It is still another object of the present
invention to provide an ink jet recording apparatus,
which can stabilize an ejection quantity, and can widen
a variation range of the ejection quantity even when a
high-speed driving operation is performed.

20 In order to achieve the above objects, according
to the present invention, there is provided an ink jet
recording apparatus comprising a recording head for
ejecting an ink from an ejection unit to cause a change
in temperature in a recording period, temperature
25 keeping means for maintaining a temperature of the
recording head at a predetermined keeping temperature
higher than an upper limit of a surrounding temperature

1 range in which recording is possible, temperature
prediction means for predicting an ink temperature in
the ejection unit in the recording period prior to
recording, and ejection stabilization means for
5 stabilizing ink ejection from the ejection unit
according to the ink temperature in the ejection unit
predicted by the temperature prediction means.

According to the present invention, there is also
provided an ink jet recording apparatus comprising a
10 recording head for ejecting an ink from an ejection
unit to cause a change in temperature in a recording
period, temperature keeping means for maintaining a
temperature of the recording head at a predetermined
keeping temperature higher than an upper limit of a
15 surrounding temperature range in which recording is
possible, surrounding temperature detection means for
detecting a surrounding temperature in the recording
period, temperature prediction means for predicting an
ink temperature in the ejection unit in the recording
20 period prior to recording using the surrounding
temperature detected by the surrounding temperature
detection means, and ejection stabilization means for
stabilizing ink ejection from the ejection unit
according to the ink temperature in the ejection unit
25 predicted by the temperature prediction means.

According to the present invention, there is also
provided an ink jet recording apparatus comprising a

1 head temperature detection member provided to a
recording head for ejecting an ink, a reference
temperature detection member provided to a main body,
and calibration means for calibrating a head
5 temperature detected by the head temperature detection
member at a predetermined timing on the basis of a
reference temperature detected by the reference
temperature detection means.

According to the present invention, there is also
10 provided a temperature calculation method for detecting
a temperature of an object, which varies according to
input energy, comprising the steps of calculating, as a
discrete value, a change in temperature of the object
upon elapse of unit time on the basis of the energy
15 input to the object in unit time, and accumulating the
discrete values upon elapse of unit time to calculate
the change in temperature of the object.

According to the present invention, there is also
provided an ink jet recording apparatus for performing
20 recording by supplying heat energy according to a
driving pulse to an ink to form a bubble based on film
boiling, and ejecting the ink from a recording head
onto a recording medium on the basis of formation of
the bubble, comprising driving means for supplying a
25 pre-driving pulse that does not cause ink ejection and
a main driving pulse that causes the ink ejection to
have a rest period between the two pulses upon ejection

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1 of one ink droplet, and rest period control means for
prolonging the rest period to conduct the heat energy
by the pre-driving pulse, thereby increasing an ink
region associated with formation of the bubble based on
5 film boiling.

According to the present invention, there is also
provided an ink jet recording apparatus for performing
recording by supplying heat energy according to a
driving pulse to an ink to form a bubble based on film
10 boiling, and ejecting the ink from a recording head
onto a recording medium on the basis of formation of
the bubble, comprising driving means for supplying at
least one driving pulse to the recording head upon
ejection of one ink droplet, and driving pulse control
15 means for limiting energy of an ejection driving pulse
that causes ink ejection of the driving pulse supplied
from the driving means after film boiling is started by
heat energy supplied according to the ejection driving
pulse.

20 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view showing an
arrangement of a preferable ink jet recording apparatus
which can embody or adopt the present invention;

Fig. 2 is a perspective view showing an
25 exchangeable cartridge;

Fig. 3 is a sectional view of a recording head;

1 Fig. 4 is a perspective view of a carriage
thermally coupled to the recording head;

 Fig. 5 is a block diagram showing a control
arrangement for executing a recording control flow;

5 Fig. 6 is a view showing the positional
relationship among sub-heaters, ejection (main)
heaters, and a temperature sensor of the head used in
this embodiment;

 Fig. 7 is an explanatory view of a divided pulse
10 width modulation driving method;

 Figs. 8A and 8B are respectively a schematic
longitudinal sectional view along an ink channel and a
schematic front view showing an arrangement of a
recording head which can adopt the present invention;

15 Fig. 9 is a graph showing the pre-pulse dependency
of the ejection quantity;

 Fig. 10 is a graph showing the temperature
dependency of the ejection quantity;

 Fig. 11 is an explanatory view associated with
20 ejection quantity control;

 Figs. 12A to 12C show ink temperature - pre-pulse
conversion tables for ejection quantity control;

 Fig. 13 shows a descent temperature table used in
temperature prediction control;

25 Figs. 14A and 14B are explanatory views showing
another arrangement for head temperature prediction;

1 Fig. 15 is a flow chart showing the outline of a
print sequence;

 Fig. 16 is a block diagram showing another control
arrangement for executing the recording control flow;

5 Figs. 17 to 19 are flow charts associated with
temperature prediction control;

 Fig. 20 shows a temperature prediction table;

 Fig. 21 is a graph showing the temperature
dependency of the vacuum hold time and the suction
10 quantity;

 Fig. 22 is a diagram showing an arrangement of a
sub-tank system;

 Fig. 23 is a graph showing output characteristics
of a temperature sensor of the recording head used in
15 the present invention;

 Fig. 24 is a flow chart showing calibration of a
temperature detection member of a recording head in the
16th embodiment;

 Fig. 25 is a flow chart showing calibration of a
20 temperature detection member of a recording head in the
17th embodiment;

 Fig. 26 is a flow chart showing calibration of a
temperature detection member of a recording head in the
18th embodiment;

25 Fig. 27 is an explanatory view for explaining a
temperature calculation system of the present
invention;

1 Fig. 28 is a graph for explaining a temperature
calculation of the present invention;

 Fig. 29 shows a temperature calculation table
according to the 19th embodiment of the present
5 invention;

 Figs. 30(a) to 30(d) are views showing temperature
calculation processes of the 19th embodiment;

 Fig. 31 is a flow chart for presuming the head
temperature according to the 19th embodiment;

10 Fig. 32 shows a temperature calculation table
according to the 20th embodiment of the present
invention;

 Fig. 33 is a perspective view showing an
arrangement of the 21st embodiment;

15 Fig. 34 shows a temperature calculation table
according to the 21st embodiment of the present
invention;

 Fig. 35 shows a target temperature table used in
the 22nd embodiment;

20 Fig. 36 is a graph showing a temperature rise
process of a recording head in the 22nd embodiment;

 Fig. 37 is an equivalent circuit diagram of a heat
conduction model in the 22nd embodiment;

 Fig. 38 is a table showing the required
25 calculation interval and the data hold time for
performing a temperature calculation;

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1 Figs. 39 to 42 are calculation tables when
ejection heaters or sub-heaters are used as a heat
source and a time constant is determined by a short or
long range member group;

5 Figs. 43A and 43B are graphs for comparing the
recording head temperature presumed by a head
temperature calculation means of the 22nd embodiment,
and the actually measured recording head temperature;

 Fig. 44 is a PWM table showing pulse widths
10 corresponding to temperature differences between the
target temperature and the head temperatures;

 Fig. 45 is a graph for explaining sub-heater
driving control;

 Fig. 46 is a table showing sub-heater driving
15 control times corresponding to temperature differences
between the target temperature and the head
temperatures;

 Fig. 47 is a flow chart showing an interrupt
routine for setting a PWM driving value and a
20 sub-heater driving time;

 Fig. 48 is a flow chart showing a main routine;

 Fig. 49 is a table showing the relationship
between the presumed head temperature and the pulse
width;

25 Fig. 50 is a table showing the relationship
between the presumed head temperature and a
pre-ejection;

1 Fig. 51 is a temperature table when pre-ejection
temperature tables are changed in units of ink colors;

 Fig. 52 is a timing chart showing the relationship
between common and segment signals in a minimum
5 ejection driving period of this embodiment;

 Figs. 53A and 53B are explanatory views showing
multi-pulse waveforms of the segment signal of this
embodiment;

 Fig. 54 is a graph showing the interval time
10 dependency of the ejection quantity;

 Fig. 55 is a sectional view showing a section of a
heater board portion of a recording head;

 Fig. 56 is a graph showing the one-dimensional
temperature distribution of the section near the heater
15 board of the recording head in a direction of
perpendicular to the heater board;

 Fig. 57 is an explanatory view associated with
ejection quantity control;

 Figs. 58 and 59 are flow charts associated with
20 ejection quantity control in a temperature prediction
control method;

 Fig. 60 is a table showing the relationship
between the surrounding temperature and the target head
temperature;

25 Figs. 61A and 61B are tables showing the
relationship between the temperature difference and the
interval time of multi-pulse PWM control;

1 Fig. 62 is an explanatory view associated with
ejection quantity control also using sub-heaters;

 Fig. 63 is a table showing multi-pulse PWM setting
values;

5 Fig. 64 is a flow chart associated with ejection
quantity control in the temperature prediction control
method also using the sub-heaters;

 Fig. 65 is a table showing the relationship
between modulation of the main pulse and interval time,
10 and the ejection quantity change rate in multi-pulse
PWM control;

 Fig. 66 is a graph showing the temperature rise
caused by heat accumulation of the recording head;

 Fig. 67 is a graph showing the relationship
15 between the interval time and the ejection possible
minimum main pulse width in the multi-pulse PWM control;

 Fig. 68 is a view showing changes in multi-pulse
condition at respective position in the 29th embodiment;

 Fig. 69 is a graph showing the relationship between
20 the pre-pulse width and the ejection possible minimum
main pulse width in the multi-pulse PWM control;

 Fig. 70 is a view showing changes in multi-pulse
condition at respective position in the 29th embodiment;

 Figs. 71 and 72 are flow charts associated with
25 ejection quantity control in the temperature prediction
method;

 Fig. 73 is a table showing the relationship

1 between the interval time and the main pulse width;

Fig. 74 is a table showing the relationship
between the pre-pulse width and the main pulse width;

Fig. 75 is a graph showing the relationship
5 between the recording head temperature and the ejection
possible minimum main pulse width in a single pulse mode;

Fig. 76 is a view showing changes in multi-pulse
condition at respective positions in the 30th embodiment;

Fig. 77 is a view showing changes in multi-pulse
10 condition at respective positions in the 30th
embodiment; and

Fig. 78 is a graph for comparing ejection quantity
variable ranges of a triple pulse method and other
methods.

15 DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of the present invention
will be described in detail hereinafter with reference
to the accompanying drawings. Fig. 1 is a perspective
view showing an arrangement of a preferable ink jet
20 recording apparatus IJRA, which can embody or adopt the
present invention. In Fig. 1, a recording head (IJH)
5012 is coupled to an ink tank (IT) 5001. As shown in
Fig. 2, the ink tank 5001 and the recording head 5012
form an exchangeable integrated cartridge (IJC). A
25 carriage (HC) 5014 is used for mounting the cartridge
(IJC) to a printer main body. A guide 5003 scans the
carriage in the sub-scan direction.

1 A platen roller 5000 scans a print medium P in the
main scan direction. A temperature sensor 5024
measures the surrounding temperature in the apparatus.
The carriage 5014 is connected to a printed board (not
5 shown) comprising an electrical circuit (the
temperature sensor 5024, and the like) for controlling
the printer through a flexible cable (not shown) for
supplying a signal pulse current and a head temperature
control current to the recording head 5012.

10 Fig. 2 shows the exchangeable cartridge, which has
nozzle portions 5029 for ejecting ink droplets. The
details of the ink jet recording apparatus IJRA with
the above arrangement will be described below. In the
recording apparatus IJRA, the carriage HC has a pin
15 (not shown) to be engaged with a spiral groove 5004 of
a lead screw 5005, which is rotated through driving
power transmission gears 5011 and 5009 in cooperation
with the normal/reverse rotation of a driving motor
5013. The carriage HC can be reciprocally moved in
20 directions of arrows a and b. A paper pressing plate
5002 presses a paper sheet against the platen roller
5000 across the carriage moving direction.
Photocouplers 5007 and 5008 serve as home position
detection means for detecting the presence of a lever
25 5006 of the carriage HC in a corresponding region, and
switching the rotating direction of the motor 5013. A
member 5016 supports a cap member 5022 for capping the

1 front surface of the recording head. A suction means
5015 draws the interior of the cap member by vacuum
suction, and performs a suction recovery process of the
recording head 5012 through an opening 5023 in the cap
5 member.

A cleaning blade 5017 is supported by a member
5019 to be movable in the back-and-forth direction.
The cleaning blade 5017 and the member 5019 are
supported on a main body support plate 5018. The blade
10 is not limited to this shape, and a known cleaning
blade can be applied to this embodiment, as a matter of
course. A lever 5021 is used for starting the suction
operation in the suction recovery process, and is moved
upon movement of a cam 5020 to be engaged with the
15 carriage HC. The movement control of the lever 5021 is
made by a known transmission means such as a clutch
switching means for transmitting the driving force from
the driving motor.

The capping, cleaning, and suction recovery
20 processes can be performed at corresponding positions
upon operation of the lead screw 5005 when the carriage
HC reaches a home position region. This embodiment is
not limited to this as long as desired operations are
performed at known timings.

25 Fig. 3 shows the details of the recording head
5012. A heater board 5100 formed by a semiconductor
manufacturing process is arranged on the upper surface

1 of a support member 5300. A temperature control heater
(temperature rise heater) 5110, formed by the same
semiconductor manufacturing process, for keeping and
controlling the temperature of the recording head 5012,
5 is arranged on the heater board 5100. A wiring board
5200 is arranged on the support member 5300, and is
connected to the temperature control heater 5110 and
ejection (main) heaters 5113 through, e.g., bonding
wires (not shown). The temperature control heater 5110
10 may be realized by adhering a heater member formed in a
process different from that of the heater board 5100
to, e.g., the support member 5300.

A bubble 5114 is produced by heating an ink by the
corresponding ejection heater 5113. An ink droplet
15 5115 is ejected from the corresponding nozzle portion
5029. The ink to be ejected flows from a common ink
chamber 5112 into the recording head.

An embodiment of the present invention will be
described below with reference to the accompanying
20 drawings. Fig. 4 is a schematic view of an ink jet
recording apparatus which can adopt the present
invention. In Fig. 4, an ink cartridge 8a has an ink
tank portion as its upper portion, and recording heads
8b (not shown) as its lower portion. The ink cartridge
25 8a is provided with a connector for receiving, e.g.,
signals for driving the recording heads 8b. A carriage
9 aligns and carries four cartridges (which store

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1 different color inks, e.g., black, cyan, magenta, and
yellow inks). The carriage 9 is provided with a
connector holder, electrically connected to the
recording heads 23, for transmitting, e.g., signals for
5 driving recording heads.

The ink jet recording apparatus includes a scan
rail 9a, extending in the main scan direction of the
carriage 9, for slidably supporting the carriage 9, and
a drive belt 9c for transmitting a driving force for
10 reciprocally moving the carriage 9. The apparatus also
includes pairs of convey rollers 10c and 10d, arranged
before and after the recording positions of the
recording heads, for clamping and conveying a recording
medium, and a recording medium 11 such as a paper
15 sheet, which is urged against a platen (not shown) for
regulating a recording surface of the recording medium
11 to be flat. At this time, the recording head 8b of
each ink jet cartridge 8a carried on the carriage 9
projects downward from the carriage 9, and is located
20 between the convey rollers 10c and 10d for conveying
the recording medium. The ejection orifice formation
surface of each recording head faces parallel to the
recording medium 11 urged against the guide surface of
the platen (not shown). Note that the drive belt 9c is
25 driven by a main scan motor 63, and the pairs of convey
rollers 10c and 10d are driven by a sub-scan motor 64
(not shown).

1 In the ink jet recording apparatus of this
embodiment, a recovery system unit is arranged at the
home position side (at the left side in Fig. 4). The
recovery system unit includes cap units 300 arranged in
5 correspondence with the plurality of ink jet cartridges
8a each having the recording head 8b. Upon movement of
the carriage 9, the cap units 300 can be slid in the
right-to-left direction and be also vertically movable.
When the carriage 9 is located at the home position,
10 the cap units 300 are coupled to the corresponding
recording heads 8b to cap them, thereby preventing an
ejection error of the ink in the ejection orifices of
the recording heads 8b. Such an ejection error is
caused by evaporation and hence an increased viscosity
15 and solidification of the attached inks.

 The recovery system unit also includes a pump unit
500 communicating with the cap units 300. When the
recording head 8b causes an ejection error, the pump
unit 500 is used for generating a negative pressure in
20 the suction recovery process executed by coupling the
cap unit 300 and the corresponding recording head 8b.
Furthermore, the recovery system unit includes a blade
401 as a wiping member formed of an elastic member such
as rubber, and a blade holder 402 for holding the blade
25 401.

 The four ink jet cartridges carried on the
carriage 9 respectively use a black (to be abbreviated

1 to as K hereinafter) ink, a cyan (to be abbreviated to
as C hereinafter) ink, a magenta (to be abbreviated to
as M hereinafter) ink, and a yellow (to be abbreviated
to as Y hereinafter) ink. The inks overlap each other
5 in this order. Intermediate colors can be realized by
properly overlapping C, M, and Y color ink dots. More
specifically, red can be realized by overlapping M and
Y; blue, C and M; and green, C and Y. Black can be
realized by overlapping three colors C, M, and Y.
10 However, since black realized by overlapping three
colors C, M, and Y has poor color development and
precise overlapping of three colors is difficult, a
chromatic edge is formed, and the ink implantation
density per unit time becomes too high. For these
15 reasons, only black is implanted separately (using a
black ink).

(Control Arrangement)

The control arrangement for executing recording
control of the respective sections of the
20 above-mentioned apparatus arrangement will be described
below with reference to Fig. 5. In Fig. 5, a CPU 60 is
connected to a program ROM 61 for storing a control
program executed by the CPU 60, and a backup RAM 62 for
storing various data. The CPU 60 is also connected to
25 the main scan motor 63 for scanning the recording head,
and the sub-scan motor 64 for feeding a recording
sheet. The sub-scan motor 64 is also used in the

1 suction operation by the pump. The CPU 60 is also
connected to a wiping solenoid 65, a paper feed
solenoid 66 used in paper feed control, a cooling fan
67, and a paper width detector LED 68 which is turned
5 on in a paper width detection operation. The CPU 60 is
also connected to a paper width sensor 69, a paper flit
sensor 70, a paper feed sensor 71, a paper eject sensor
72, and a suction pump position sensor 73 for detecting
the position of the suction pump. The CPU 60 is also
10 connected to a carriage HP sensor 74 for detecting the
home position of the carriage, a door open sensor 75
for detecting an open/closed state of a door, and a
temperature sensor 76 for detecting the surrounding
temperature.

15 The CPU 60 is also connected to a gate array 78
for performing supply control of recording data to the
four color heads, a head driver 79 for driving the
heads, the ink cartridges 8a for four colors, and the
recording heads 8b for four colors. Fig. 5
20 representatively illustrates the Bk (black) ink
cartridge 8a and the Bk recording head 8b. The head 8b
has main heaters 8c for ejecting the ink, sub-heaters
8d for performing temperature control of the head, and
temperature sensors 8e for detecting the head
25 temperature.

Fig. 6 is a view showing a heater board (H.B) 853
of the head used in this embodiment. Ejection unit

1 arrays 8g on which the temperature control (sub)
heaters 8d and the ejection (main) heaters 8c are
arranged, the temperature sensors 8e, driving elements
8h are formed on a single substrate to have the
5 positional relationship shown in Fig. 6. When the
elements are arranged on the single substrate,
detection and control of the head temperature can be
efficiently performed, and a compact head and a simple
manufacturing process can be realized. Fig. 6 also
10 shows the positional relationship of outer wall
sections 8f of a top plate for separating the H·B into
a region filled with the ink, and the remaining region.
(First Embodiment)

 An embodiment of the present invention will be
15 described in detail below with reference to the
accompanying drawings. In this embodiment, a
temperature detection member capable of directly
detecting the temperature of the recording head of the
above-mentioned recording apparatus, and a temperature
20 calculation circuit for this member are added.

 In Fig. 6, the head temperature sensors 8e are
arranged on the H·B 853 of the recording head together
with the ejection heaters 8g and the sub-heaters 8d,
and are thermally coupled to the heat source of the
25 recording head. Therefore, each temperature sensor 8e
can easily detect the temperature of the ink in the
common ink chamber surrounded by the top plate 8f, but

1 is easily influenced by heat generated by the ejection
heaters and the sub-heaters. Thus, it is difficult to
detect the temperature of the ink during the driving
operation of these heaters. For this reason, in this
5 embodiment, as the temperature of the recording head
including the ink in the ejection unit, a value
actually measured by the temperature detection member
is used in a static state, and a predicted value is
used in a dynamic state (e.g., in a recording mode
10 suffering from a large temperature drift), thereby
detecting the ink temperature in the ejection unit with
high precision.

(Summary of Ejection Stabilization)

In this embodiment, in execution of recording by
15 ejecting ink droplets from the recording head, the
temperature of the recording head is maintained at a
keeping temperature set to be higher than the
surrounding temperature using the temperature detection
member and heating members (sub-heaters) provided to
20 the recording head. In addition to the detection
temperature of the temperature detection member, the
ink temperature drift of the ejection unit is predicted
on the basis of energy to be supplied to the recording
head, and the thermal time constant of the ejection
25 unit, and ejection is stabilized according to the
predicted ink temperature. It is difficult in terms of
cost to equip the temperature detection member for

1 directly detecting the temperature of the recording
head in the ink jet recording apparatus using the IJC
like in this embodiment. In addition, a countermeasure
against static electricity required for joint points
5 between a temperature measurement circuit and the IJC
relatively complicates the recording apparatus. From
this viewpoint, the arrangement of such a circuit is
disadvantageous. However, in order to detect the
temperature of the recording head including the ink in
10 the ejection unit prior to recording, the temperature
detection member provided to the recording head should
be utilized to simplify calculation processing, and to
improve precision. This embodiment exemplifies the
exchangeable recording head. Of course, a permanent
15 type recording head, which need not be exchanged, may
be used. In this case, the above-mentioned
disadvantages are relaxed as a matter of course.

In the present invention, the target head
temperature in the recording mode is set at a
20 temperature sufficiently higher than the upper limit of
a surrounding temperature range within which the ink
jet recording apparatus of the present invention is
assumed to be normally used. In one driving method of
this control, the temperature of the recording head is
25 increased to and maintained at the keeping temperature
higher than the surrounding temperature using the
sub-heaters, and PWM ejection quantity control (to be

1 described later) based on the predicted ink temperature
drift is made to obtain a constant ejection quantity.
More specifically, when the ejection quantity is
stabilized, a change in density in one line or one page
5 can be eliminated. At the same time, when the
recording condition and the recovery condition are
optimized, deterioration of image quality caused by the
ejection error and ink overflow on a recording sheet
can also be prevented.

10 (PWM Control)

The PWM ejection quantity control method of this
embodiment will be described in detail below with
reference to the accompanying drawings. Fig. 7 is a
view for explaining divided pulses according to this
15 embodiment. In Fig. 7, V_{OP} represents an operational
voltage, P_1 represents the pulse width of the first
pulse (to be referred to as a pre-pulse hereinafter) of
a plurality of divided heat pulses, P_2 represents an
interval time, and P_3 represents the pulse width of the
20 second pulse (to be referred to as a main pulse
hereinafter). T_1 , T_2 , and T_3 represent times for
determining the pulse widths P_1 , P_2 , and P_3 . The
operational voltage V_{OP} represents electrical energy
necessary for causing an electrothermal converting
25 element applied with this voltage to generate heat
energy in the ink in an ink channel constituted by the
heater board and the top plate. The value of this

1 voltage is determined by the area, resistance, and film
structure of the electrothermal converting element, and
the channel structure of the recording head.

The PWM ejection quantity control of this
5 embodiment can also be referred to as a pre-pulse width
modulation driving method. In this control, in
ejection of one ink droplet, the pulses respectively
having the widths P_1 , P_2 , and P_3 are sequentially
applied, and the pre-pulse width is modulated according
10 to the ink temperature. The pre-pulse is a pulse for
mainly controlling the ink temperature in the channel,
and plays an important role of the ejection quantity
control of this embodiment. The pre-heat pulse width
is preferably set to be a value, which does not cause a
15 bubble production phenomenon in the ink by heat energy
generated by the electrothermal converting element
applied with this pulse. The interval time assures a
time for transmitting the energy of the pre-pulse to
the ink in the ink channel. The main pulse produces a
20 bubble in the ink in the ink channel, and ejects the
ink from an ejection orifice. The width P_3 of the main
pulse is preferably determined by the area, resistance,
and film structure of the electrothermal converting
element, and the channel structure of the recording
25 head.

The operation of the pre-pulse in a recording head
having a structure shown in, e.g., Figs. 8A and 8B will

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1 be described below. Figs. 8A and 8B are respectively a
schematic longitudinal sectional view along an ink
channel and a schematic front view showing an
arrangement of a recording head which can adopt the
5 present invention. In Figs. 8A and 8B, an
electrothermal converting element (ejection heater) 21
generates heat upon application of the divided pulses.
The electrothermal converting element 21 is arranged on
a heater board together with an electrode wire for
10 applying the divided pulses to the element 21. The
heater board is formed of a silicon layer 29, and is
supported by an aluminum plate 31 constituting the
substrate of the recording head. A top plate 32 is
formed with grooves 35 for constituting ink channels
15 23, and the like. When the top plate 32 and the heater
board (aluminum plate 31) are joined, the ink channels
23, and a common ink chamber 25 for supplying the ink
to the channels are constituted. Ejection orifices 27
(the hole area corresponds to a diameter of $20\ \mu$) are
20 formed in the top plate 32, and communicate with the
ink channels 23.

In the recording head shown in Figs. 8A and 8B,
when the operational voltage $V_{op} = 18.0$ (V) and the main
pulse width $P_3 = 4.114$ [μ sec] are set, and the pre-pulse
25 width P_1 is changed within a range between 0 to 3.000
[μ sec], the relationship between an ejection quantity
 V_d [pl/drop] and the pre-pulse width P_1 [μ sec] shown in

1 Fig. 9 is obtained. Fig. 9 is a graph showing the
pre-pulse width dependency of the ejection quantity.
In Fig. 9, V_0 represents the ejection quantity when $P_1 =$
0 [μ sec], and this value is determined by the head
5 structure shown in Figs. 8A and 8B. For example, $V_0 =$
18.0 [pl/drop] in this embodiment when a surrounding
temperature $T_R = 25^\circ\text{C}$.

As indicated by a curve a in Fig. 9, the ejection
quantity V_d is linearly increased according to an
10 increase in pre-pulse width P_1 when the pulse width P_1
changes from 0 to $P_{1\text{LMT}}$. The change in quantity loses
linearity when the pulse width P_1 falls within a range
larger than $P_{1\text{LMT}}$. The ejection quantity V_d is
saturated, i.e., becomes maximum at the pulse width
15 $P_{1\text{MAX}}$. The range up to the pulse width $P_{1\text{LMT}}$ where the
change in ejection quantity V_d shows linearity with
respect to the change input pulse width P_1 is effective
as a range where the ejection quantity can be easily
controlled by changing the pulse width P_1 . For
20 example, in this embodiment indicated by the curve a,
 $P_{1\text{LMT}} = 1.87$ (μ s), and the ejection quantity at that time
was $V_{\text{LMT}} = 24.0$ [pl/drop]. The pulse width $P_{1\text{MAX}}$ when the
ejection quantity V_d was saturated was $P_{1\text{MAX}} = 2.1$ [μ s],
and the ejection quantity at that time was $V_{\text{MAX}} = 25.5$
25 [pl/drop].

When the pulse width is larger than $P_{1\text{MAX}}$, the
ejection quantity V_d becomes smaller than V_{MAX} . This

1 phenomenon produces a small bubble (in a state
immediately before film boiling) on the electrothermal
converting element upon application of the pre-pulse
having the pulse width within the above-mentioned
5 range, the next main pulse is applied before this
bubble disappears, and the small bubble disturbs bubble
production by the main pulse, thus decreasing the
ejection quantity. This region is called a pre-bubble
region. In this region, it is difficult to perform
10 ejection quantity control using the pre-pulse as a
medium.

When the inclination of a line representing the
relationship between the ejection quantity and the
pulse width within a range of $P_1 = 0$ to P_{1LMT} [μs] is
15 defined as a pre-pulse dependency coefficient, the
pre-pulse dependency coefficient is given by:

$$KP = \Delta Vdp / \Delta P_1 \text{ [pl}/\mu\text{sec}\cdot\text{drop}]$$

This coefficient KP is determined by the head
structure, the driving condition, the ink physical
20 property, and the like independently of the
temperature. More specifically, curves b and c in
Fig. 9 represent the cases of other recording heads.
As can be understood from Fig. 9, the ejection
characteristics vary depending on recording heads. In
25 this manner, since the upper limit value P_{1LMT} of the
pre-pulse P_1 varies depending on different types of
recording heads, the upper limit value P_{1LMT} for each

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1 recording head is determined, as will be described
 later, and ejection quantity control is made. In
 parentheses, in the recording head and the ink
 indicated by the curve a of this embodiment, $KP = 3.209$
 5 $[pl/\mu sec \cdot drop]$.

As another factor for determining the ejection
 quantity of the ink jet recording head, the ink
 temperature of the ejection unit (which may often be
 substituted with the temperature of the recording head)
 10 is known. Fig. 10 is a graph showing the temperature
 dependency of the ejection quantity. As indicated by a
 curve a in Fig. 10, the ejection quantity V_d linearly
 increases as an increase in temperature T_H (equal to the
 ink temperature in the ejection unit since
 15 characteristics in this case are static temperature
 characteristics). When the inclination of this line is
 defined as a temperature dependency coefficient, the
 temperature dependency coefficient is given by:

$$KT = \Delta V_d T / \Delta T_H [pl/^\circ C \cdot drop]$$

20 This coefficient KT is determined by the head
 structure, the ink physical property, and the like
 independently of the driving condition. In Fig. 10,
 curves b and c also represent the cases of other
 recording heads. For example, in the recording head of
 25 this embodiment, $KT = 0.3 [pl/^\circ C \cdot drop]$.

Fig. 11 shows an actual control diagram of the
 relationships shown in Figs. 9 and 10. In Fig. 11, T_0

1 represents a keeping temperature of the recording head.
When the ink temperature of the ejection unit is lower
than T_0 , the recording head is heated by the
sub-heaters. Therefore, the PWM control as the
5 ejection quantity control according to the ink
temperature is performed at a temperature equal to or
higher than T_0 . In the present invention, the keeping
temperature is set to be higher than a normal
surrounding temperature. As described above, since the
10 ejection quantity control is preferably performed using
the pre-pulse, the width of which is smaller than the
pre-bubble region, and the temperature range capable of
performing the PWM control is limited to some extent,
the ejection quantity can be stabilized easily at a
15 high keeping temperature in consideration of the
temperature rise of the recording head itself.

For example, when the keeping temperature is set
at 20°C , the heating operation of the sub-heaters is
almost unnecessary when the recording apparatus is used
20 in an ordinary environment, and a merit of no wait time
can be obtained. However, an upper limit temperature T_L
capable of performing the PWM control in this case is
 38°C . In a high-temperature environment as high as
about 30°C , even when the temperature of the recording
25 head itself is increased, the temperature range capable
of performing the ejection quantity control is
narrowed. In contrast to this, according to the

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1 present invention, since the keeping temperature is set
at 36°C, the upper limit temperature T_L is set at 54°C,
and the temperature range capable of performing the
ejection quantity control can be prevented from being
5 narrowed in an ordinary environment. Even when the
temperature of the recording head itself is increased
more or less, recording can be satisfactorily performed
in a stable ejection quantity. When the PWM control is
made by directly measuring the temperature of the
10 recording head using a temperature sensor, it is
advantageous since an adverse influence such as a
ripple of the detection temperature due to heating of
the sub-heater and heat generation in the recording
mode can be eliminated. However, in this embodiment,
15 the ink temperature of the ejection unit is directly
measured in a state with a small temperature drift like
in a non-recording mode, and the temperature in the
recording mode with a large temperature drift is
predicted from energy to be supplied to the recording
20 head and the thermal time constant of the recording
head including the ink in the ejection unit. For this
reason, the above-mentioned adverse influence can be
eliminated from the beginning. Furthermore, the ink
temperature of the ejection unit, which has been
25 increased too much, is decreased mainly by heat
radiation to the recording head, and the ink
temperature can be decreased earlier as the temperature

1 decrease speed of the recording head is higher. For
this reason, it is more advantageous as the difference
between the keeping temperature and the surrounding
temperature in the recording mode is larger.

5 The temperature range described as a "PWM control
region" in Fig. 11 is a temperature range capable of
stabilizing the ejection quantity, and in this
embodiment, this range corresponds to a range between
34°C and 54°C of the ink temperature of the ejection
10 unit. Fig. 11 shows the relationship between the ink
temperature of the ejection unit and the ejection
quantity when the pre-pulse is changed by 11 steps.
Even when the ink temperature of the ejection unit
changes, the pre-pulse width is changed for each
15 temperature step width ΔT according to the ink
temperature, so that the ejection quantity can be
controlled within the width ΔV with respect to a target
ejection quantity V_{d0} .

Fig. 12A shows a correspondence table between the
20 ink temperature and the pre-pulse. In this embodiment,
the exchangeable IJC is used as the recording head.
When the ejection quantities vary depending on
cartridges, the correspondence table between the ink
temperature and the pre-pulse may be changed in
25 correspondence with heads. For example, in the case of
a cartridge having a relatively small ejection
quantity, a table shown in Fig. 12B may be used. In

1 the case of a cartridge having a relatively large
ejection quantity, a table shown in Fig. 12C may be
used. Furthermore, a table may be provided according
to the pre-pulse dependency coefficient or the
5 temperature dependency coefficient of the ejection
quantity.

(Temperature Prediction Control)

Presumption of the ink temperature of the ejection
unit in this embodiment is basically performed using
10 the distribution of a power ratio calculated from the
number of dots of image data to be printed on the basis
of the actually measured value from the temperature
detection member in the non-recording mode with a small
temperature drift. In this embodiment, the power ratio
15 is calculated in each reference period obtained by
dividing a recording period at predetermined intervals,
and the temperature prediction and PWM control are also
sequentially performed in each reference period. The
reason why the number of dots (print duty) is not
20 merely used is that energy to be supplied to a head
chip varies according to a variation in pre-pulse value
even when the number of dots remains the same. Using
the concept of the "power ratio", a single table can be
used even when the pre-pulse value is changed by the
25 PWM control. Of course, a calculation may be made
while temporarily fixing the pulse width to a

1 predetermined value depending on required precision of
the predicted ink temperature.

In this embodiment, the temperature of the
recording head is maintained at the keeping temperature
5 set to be higher than the surrounding temperature by
properly driving the sub-heaters according to the
temperature detected by the temperature detection
member. For this reason, as for an increase or
decrease in ink temperature, the temperature rise due
10 to heat generation of the ejection heaters and heat
radiation based on the thermal time constant of the
recording head need only be predicted with reference to
a control temperature. In this case, until the
temperature of an aluminum base plate having a large
15 heat capacity, which is a major heat radiation
destination in a temperature rise state, reaches a
predetermined temperature, the heat radiation
characteristics may often vary. In this case, since
the object of utilization of the temperature detection
20 member in this embodiment is to detect the ink
temperature in a static state with a small temperature
drift, the sub-heaters for keeping the temperature and
the temperature detection member may be arranged
adjacent to the aluminum base plate as one constituting
25 member of the recording head since no serious problem
is posed when they are arranged at positions relatively
thermally separated from the ejection heaters.

1 In this embodiment, a sum of the keeping
temperature and a value obtained by accumulating
increased temperature remainders in all the effective
reference time periods (the increased temperature
5 remainder is not 0) before an objective reference time
period in which the ink temperature is presumed is
determined as the ink temperature during the objective
reference time period with reference to a descent
temperature table in Fig. 13, which shows increased
10 temperature remainders from the keeping temperature
according to the power ratio during a given reference
time period in units of elapse times from the reference
time period. A print time for one line is assumed to
be 0.7 sec, and a time period (0.02 sec) obtained by
15 dividing this print time by 35 is defined as the
reference time period.

For example, if recording is performed for the
first time at a power ratio of 20% during the first
reference time period, 80% during the second reference
20 time period, and 50% during the third reference time
period after the temperature keeping operation is
completed, the ink temperature of the ejection unit
during the fourth reference time period can be presumed
from the increased temperature remainders of the three
25 reference time periods so far. More specifically, the
increased temperature remainder during the first
reference time period is 85×10^{-3} deg (@ in Fig. 13)

1 since the power ratio is 20% and the elapse time is
0.06 sec; the increased temperature remainder during
the second reference time period is 369×10^{-3} deg (ⓐ in
Fig. 13) since the power ratio is 80% and the elapse
5 time is 0.04 sec; and the increased temperature
remainder during the third reference time period is 250
 $\times 10^{-3}$ deg (ⓒ in Fig. 13) since the power ratio is 50%
and the elapse time is 0.02 sec. Therefore, when these
remainders are accumulated, we have 704×10^{-3} deg, and
10 36.704°C as the sum of this value and 36°C are
predicted as the ink temperature of the ejection unit
during the fourth reference time period.

Presumption of the ink temperature and setting of
the pulse width are performed as follows in practice.
15 The pre-pulse value during the first reference period
is obtained from the predicted ink temperature (equal
to the keeping temperature if it is immediately after
the temperature keeping operation is completed) at the
beginning of the print operation during the first
20 reference time period with reference to Fig. 12A, and
is set on the memory. Then, the power ratio during the
first reference time period is calculated based on the
number of dots (number of times of ejection) obtained
from image data, and the pre-pulse value. The
25 calculated power ratio is substituted in the descent
temperature table (Fig. 13) (with reference to the
table) to predict the ink temperature at the end of the

1 print operation during the first reference time period
(i.e., at the beginning of the print operation during
the second reference time period). The ink temperature
can be presumed by adding the increased temperature
5 remainder obtained from Fig. 13 to the keeping
temperature. Subsequently, the pre-pulse value during
the second reference time period is obtained from the
predicted ink temperature at the beginning of the print
operation during the second reference time period with
10 reference to Fig. 12A, and is set on the memory.

Thereafter, the power ratio is calculated in turn
based on the number of dots in the corresponding
reference time period and the predicted ink
temperature, and increased temperature remainders
15 associated with the objective reference time periods
are accumulated. Thereafter, after the pre-pulse
values during all the reference time periods in one
line are set, the 1-line print operation is performed
according to the set pre-pulse values.

20 With the above-mentioned control, the actual
ejection quantity can be stably controlled
independently of the ink temperature, and a uniform
recorded image with high quality can be obtained.

Recording signals, and the like sent through an
25 external interface are stored in a reception buffer 78a
in the gate array 78. The data stored in the reception
buffer 78a is developed to a binary signal (0, 1)

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1 indicating "to eject/not to eject", and the binary
signal is transferred to a print buffer 78b. The CPU
60 can refer to the recording signals from the print
buffer 78b as needed. Two line duty buffers 78c are
5 prepared in the gate array 78. Each line duty buffer
stores print duties (ratios) of areas obtained by
dividing one line at equal intervals (into, e.g., 35
areas). The "line duty buffer 78c1" stores print duty
data of the areas of a currently printed line. The
10 "line duty buffer 78c2" stores print duty data of the
areas of a line next to the currently printed line.
The CPU 60 can refer to the print duties of the
currently printed line and the next line any time, as
needed. The CPU 60 refers to the line duty buffers 78c
15 during the above-mentioned temperature prediction
control to obtain the print duties of the areas.
Therefore, the calculation load on the CPU 60 can be
reduced.

 In this embodiment, a recording operation is
20 inhibited or an alarm is generated for a user until the
temperature keeping operation is completed, and the ink
temperature associated with the ejection quantity
control is presumed after the temperature keeping
operation is completed. Under these conditions,
25 prediction of the ink temperature can be simplified
since the control is made under an assumption that the
temperature of the aluminum base plate associated with

1 heat radiation is maintained at a temperature equal to
or higher than the keeping temperature. However, if a
surrounding temperature detection means (the
temperature sensor 5024 in Fig. 1) is used, since the
5 temperature of the aluminum base plate at a desired
timing can be predicted even before the temperature
keeping operation is completed, the ink temperature of
the ejection unit is detected using the predicted
temperature as a reference temperature so as to allow
10 recording before completion of the temperature keeping
operation. Since a time required until the temperature
keeping operation is completed can be calculated and
predicted if the surrounding temperature detection
means is used, the time of a temperature keeping timer
15 may be changed according to the predicted time.

In this embodiment, double-pulse PWM control is
performed to control the ejection quantity.
Alternatively, single-pulse PWM control or PWM control
using three or more pulses may be used.

20 According to the present invention, the keeping
temperature is set to be higher than a normal
surrounding temperature to widen the temperature range
capable of performing the ejection quantity control to
a high-temperature region. When the ink temperature
25 reaches a non-control region at a higher temperature in
which ejection quantity control is impossible, the
temperature prediction may be restarted from the

1 beginning after the carriage scan speed is decreased or
after the carriage scan start timing is delayed.

(Second Embodiment)

5 A method of presuming the current temperature from
a print ratio (to be referred to as a print duty
hereinafter), and controlling a recovery sequence for
stabilizing ejection in an ink jet recording apparatus
will be described below. In the present invention,
since the keeping temperature in a print mode is set to
10 be higher than a surrounding temperature, the ink in
the ejection unit is easily evaporated, and it is
important to perform recovery control according to the
thermal history of the recording head. In this
embodiment, a pre-ejection condition is changed
15 according to the presumed ink temperature of the
ejection unit during recording and at the end of
recording.

At a high temperature, the ink in the ejection
unit is easily evaporated. In particular, when there
20 is a nozzle which is not used by chance according to
recording data, the ink in only the nozzle is
evaporated, and cannot be easily ejected from this
nozzle. Thus, the pre-ejection interval or the number
of times of pre-ejection can be changed according to
25 the presumed ink temperature in the recording mode. In
this embodiment, the number of times of pre-ejection is
changed as shown in Table 1 below according to the

1 maximum ink temperature in the recording mode. At the
same time, as the temperature in a pre-ejection mode is
higher, the ejection quantity is increased. For this
reason, the ejection quantity is suppressed by
5 decreasing the pulse width according to the ink
temperature in the pre-ejection mode by the same PWM
control as in the first embodiment. In this case, a
pre-pulse table may be modified to obtain relatively
higher energy than in the recording mode in
10 consideration of the object of the pre-ejection.

Table 1

	Maximum Ink Temperature (°C)	Number of Times of Pre-ejection
	30 to 40	12
15	40 to 50	18
	more than 50	24

As the temperature is higher, the temperature
variations among nozzles are increased. For this
reason, the distribution of the number of times of
20 pre-ejection may be optimized. For example, as the
temperature becomes higher, control may be made to
increase a difference between the numbers of times of
pre-ejection of the nozzle end portions and the central
portion as compared to that at room temperature.
25

When a plurality of heads are arranged, different
pre-ejection temperature tables may be prepared in
units of ink colors. When the head temperature is

1 high, the viscosity of Bk (black) containing a larger
amount of dye as compared to Y (yellow), M (magenta),
and C (cyan) tends to be increased. For this reason,
control may be made to increase the number of times of
5 pre-ejection. When the plurality of heads have
different head temperatures, pre-ejection control may
be made in units of heads.

When the number of nozzles is large, nozzles 49
may be divided into two regions, as shown in Fig. 14A
10 showing the surface of the head, and the ink
temperature may be presumed in units of divided
regions. As shown in the block diagram of Fig. 14B,
counters 51 and 52 for independently obtaining print
duties are provided in correspondence with the two
15 nozzle regions, and the ink temperatures are presumed
on the basis of the independently obtained print
duties. Then, the pre-ejection conditions can be
independently set. Thus, an error in ink temperature
prediction caused by the print duty can be eliminated,
20 and more stable ejection can be expected. Note that in
Fig. 14B, a host computer 50 is connected to the
counters 51 and 52, and the same reference numerals in
Fig. 14B denote the same parts as in Figs. 1 and 5.

The total number of times of ejection of each
25 nozzle may be counted, and the degree of evaporation of
the ink in each nozzle may be presumed in combination
with the presumed ink temperature. The distribution of

1 the number of times of pre-ejection may be optimized in
correspondence with these presumed values. Such
control can be easily realized by the arrangement of
the present invention, and a remarkable effect can also
5 be expected.

(Third Embodiment)

This embodiment exemplifies a case wherein a
predetermined recovery means is operated at intervals
which are optimally set according to the history of the
10 ink temperature in an ejection unit within a
predetermined period of time. The recovery means to be
controlled in this embodiment is wiping means, which is
executed at predetermined time intervals during a
continuous print operation (in a cap open state) so as
15 to stabilize ejection. The wiping means to be
controlled in this embodiment is executed for the
purpose of removing an unnecessary liquid such as an
ink, vapor, or the like, and a solid-state foreign
matter such as paper particles, dust, or the like
20 attached onto an orifice formation surface.

This embodiment pays attention to the fact that
the wet quantity due to, e.g., the ink varies depending
on the head temperature, and evaporation of the wet,
which makes removal of the ink or the foreign matter
25 difficult, is associated with the head temperature (the
temperature of the orifice formation surface). Thus,
since the temperature of the orifice formation surface

1 has a strong correlation with the ink temperature in
the ejection unit, ink temperature prediction can be
applied to wiping control. Since the above-mentioned
wet quantity and evaporation of the wet associated with
5 wiping has a stronger correlation with the temperature
of the orifice formation surface in the recording mode
than the head temperature upon execution of wiping, a
temperature presuming means in the recording mode of
this embodiment can be suitably applied.

10 Fig. 15 is a flow chart showing the outline of a
print sequence of the ink jet recording apparatus of
this embodiment. When a print signal is input, the
print sequence is executed (step S1). A pre-ejection
timer is set according to the ink temperature at that
15 time, and is started (step S2). Furthermore, a wiping
timer is similarly set according to the ink temperature
at that time, and is started (step S3). If no paper
sheet is stocked, paper sheets are supplied (steps S4
and S5), and thereafter, as soon as a data input
20 operation is completed, a carriage scan (printing scan)
operation is performed to print data for one line
(steps S6 and S7).

When the print operation is to be ended, the paper
sheet is discharged, and the control returns to a
25 standby state (steps S8 to S10); when the print
operation is to be continued, the paper sheet is fed by
a predetermined amount, and the tail end of the paper

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1 sheet is checked (steps S11 to S14). The wiping and
pre-ejection timers, which have been set according to
the average ink temperature in the print mode, are
checked and re-set, and after a wiping or pre-ejection
5 operation is performed as needed, these timers are
restarted (steps S15 and S16). At this time, the
average ink temperature is calculated regardless of the
presence/absence of execution of the operation (steps
S151 and S161), and the wiping and pre-ejection timers
10 are re-set according to the calculated average
temperature (steps S153, S155, S163, and S165).

More specifically, in this embodiment, since the
wiping and pre-ejection timings are finely re-set
according to the average ink temperature every time a
15 line print operation is performed, the optimal wiping
and pre-ejection operations according to ink
evaporation or wet conditions can be performed. After
the end of the predetermined recovery operations, and
the completion of the data input operation, the
20 above-mentioned steps are repeated to perform the
printing scan operation again.

Table 2 below serves as a correspondence table
between the pre-ejection interval and the number of
times of pre-ejection according to the average ink
25 temperature for last 12 sec, and as for the wiping
interval, serves as a correspondence table according to
the average ink temperature for last 48 sec. In this

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1 embodiment, as the average head temperature becomes
higher, the interval is set to be shorter, and the
number of times of pre-ejection is decreased. On the
contrary, as the average head temperature becomes
5 lower, the interval is set to be longer, and the number
of times of pre-ejection is increased. The interval
and the number of times of pre-ejection can be
appropriately set in consideration of the ejection
characteristics according to evaporation/viscosity
10 increase characteristics of the ink, and
characteristics such as a change in density. For
example, when an ink, which contains a large quantity
of a nonvolatile solvent, and is assumed to suffer from
a decrease in viscosity due to the temperature rise
15 rather than an increase in viscosity due to
evaporation, is used, the pre-ejection interval may be
set to be longer when the temperature is high.

20

25

Table 2

Presumed Temperature (°C)	Presumption for Last 12 sec		Presumption for Last 48 sec	Presumption for Last 12 hours
	Pre-ejection		Wiping Interval	Suction Interval
	Interval (sec)	No. of Pulses	(sec)	(hour)
30 to 40	9	12	36	60
40 to 50	6	8	24	48
more than 50	3	4	12	3

As for wiping, since a normal liquid ink tends to increase the wet quantity and difficulty of removal as the temperature becomes higher, the wiping operation is frequently performed at a high temperature in this embodiment. This embodiment has exemplified a case wherein one recording head is arranged. However, in an apparatus which realizes color recording or high-speed recording using a plurality of heads, the recovery conditions may be controlled based on the average ink temperature in units of recording heads, or the recovery means may be simultaneously operated according to a recording head requiring the shortest interval. (Fourth Embodiment)

This embodiment exemplifies an example of a suction recovery means according to the past average ink temperature for a relatively long period of time as another example of recovery control based on the

1 presumed average ink temperature like in the third
embodiment. The recording head of the ink jet
recording apparatus is often arranged for the purpose
of stabilizing the meniscus shape at a nozzle opening,
5 such that a negative head pressure is attained at the
nozzle opening. An unexpected bubble in an ink channel
causes various problems in the ink jet recording
apparatus, and tends to pose problems particularly in a
system maintained at the negative head pressure.

10 More specifically, even in a non-recording state,
i.e., when the ink is merely left as it is, a bubble,
which disturbs normal ejection, is grown in the ink
channel due to dissociation of a gas contained in the
ink or gas exchange through the ink channel

15 constituting members, thus posing a problem. The
suction recovery means is prepared for the purpose of
removing such a bubble in the ink channel and the ink
whose viscosity is increased due to evaporation at the
distal end portion of the nozzle opening. Ink

20 evaporation changes depending on the head temperature,
as described above. The growth of a bubble in the ink
channel is influenced more easily by the ink
temperature, and the bubble tends to be produced as the
temperature is higher. In this embodiment, as shown in

25 Table 2 above, the suction recovery interval is set
according to the average ink temperature for last 12
hours, and a suction recovery operation is frequently

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1 performed as the average ink temperature is higher.
The average temperature may be re-set for, e.g., every
page.

When the past average ink temperature over a
5 relatively long period of time is to be presumed using
a plurality of heads, as shown in Fig. 4 presented
previously, after the plurality of heads are thermally
coupled, the average ink temperature of the plurality
of heads may be presumed on the basis of the average
10 duty of the plurality of heads, and the average
temperature detected by the temperature detection
member, so that control may be simplified under an
assumption that the plurality of heads are almost
identical. In Fig. 4, the heads are thermally coupled
15 as follows. That is, the recording heads are mounted
on a carriage which is partially (including a common
support portion for the heads) or entirely formed of a
material having a high heat conductivity such as
aluminum, so that base portions having a high heat
20 conductivity of the recording heads are in direct
contact with the carriage.

As has been described above in the first
embodiment, a future head temperature can be easily
predicted based on the average ink temperature.
25 Therefore, optimal suction recovery control may be set
in consideration of a future ejection condition.

1 For example, even when anxiety for an ejection
error upon execution of a high-duty print operation at
the current ink temperature is present, if it is known
that no high-duty print operation will be performed in
5 the future, the suction operation is postponed at the
present time, and is performed after a recording medium
is discharged, thereby shortening the total print time.
(Fifth Embodiment)

 This embodiment exemplifies an example of recovery
10 system control according to the history of a
temperature presumed from the temperature detected by
the temperature detection member of the recording head,
and the print duty. A foreign matter such as the ink
deposited on the orifice formation surface often
15 deviates the ejection direction, and sometimes causes
an ejection error. The wiping means is arranged as a
means for recovering such deteriorated ejection
characteristics. In some cases, a wiping member having
a stronger frictional contact force may be prepared, or
20 wiring characteristics may be improved by temporarily
changing a wiping condition.

 In this embodiment, the entrance amount (thrust
amount) of the wiping member comprising a rubber blade
to the orifice formation surface is increased to
25 temporarily improve the wiping characteristics (rubbing
mode). It was experimentally demonstrated that
deposition of a foreign matter requiring rubbing was

1 associated with the wet ink quantity, the residual wet
ink quantity after wiping, and evaporation of the wet
ink, and had a strong correlation with the number of
times of ejection, and the temperature upon ejection.
5 In this embodiment, the rubbing mode is controlled
according to the number of times of ejection weighted
by the ink temperature. Table 3 below shows weighting
coefficients to be multiplied with the number of times
of ejection as fundamental data of a print duty
10 according to the ink temperature presumed from the
print duty. More specifically, as the temperature is
higher at which a wet or residual wet ink tends to
appear, the number of times of ejection serving as an
index of a deposit is controlled to be increased.

15 Table 3

Presumed Temperature (°C)	Weighting Coefficient for No. of Pulses
30 to 40	1.0
40 to 50	1.2
20 more than 50	1.4

When the weighted number of times of ejection
reaches five million times, the rubbing mode is
enabled. The rubbing mode is effective for removing a
25 deposit, but may cause mechanical damage to the orifice
formation surface due to the strong frictional contact
force. Therefore, it is preferable to minimize
execution of the rubbing mode. When control is made

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1 based on data having a direct correlation with the
deposition of a foreign matter like in this embodiment,
this allows a simple arrangement, and high reliability.
In a system having a plurality of heads, the print duty
5 may be managed in units of colors, and the rubbing mode
may be controlled in units of ink colors having
different deposition characteristics.

As has been described above in the first
embodiment, a future ink temperature can be easily
10 predicted. Therefore, optimal control may be set using
the "weighted number of times of ejection" in
consideration of a future condition in the calculation
of the "weighted number of times of ejection".

(Sixth Embodiment)

15 This embodiment exemplifies an example of suction
recovery control like in the fourth embodiment. In
this embodiment, in addition to presumption of a bubble
(non-print bubble) grown when the ink is left as it is,
a bubble (print bubble) grown in the print mode is also
20 presumed, thus allowing presumption of bubbles in the
ink channel with high precision. As described above,
evaporation of the ink changes depending on the ink
temperature. The growth of a bubble in the ink channel
is influenced more easily by the ink temperature, and
25 the bubble tends to be produced as the temperature is
higher. For this reason, it is obvious that the
non-print bubble can be presumed by counting a

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1 non-print time weighted by the ink temperature. The
print bubble tends to be grown as the ink temperature
upon ejection is higher, and also has a positive
correlation with the number of times of ejection.

5 Thus, it is also obvious that the print bubble can
be presumed by counting the number of times of
ejections weighted by the ink temperature in the
ejection unit. In this embodiment, as shown in Table 4
below, the number of points according to a non-print
10 time (non-print bubble), and the number of points
according to the number of times of ejections (print
bubble) are set, and when a total number of points
reaches one hundred million, it is determined that the
bubble in the ink channel may adversely influence
15 ejection, and the suction recovery operation is
performed, thereby removing the bubble.

Table 4

20	Presumed Temperature (°C)	No. of Points According to Non-print Time (point/sec)	No. of Points According to No. of Dots (point/sec)
	30 to 40	455	56
	40 to 50	588	65
	more than 50	769	74

25 Matching between the number of points of the print
bubble and that of the non-print bubble was
experimentally determined such that the numbers of

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1 points were equal to each other when ejection errors
were independently caused by these factors under a
constant temperature condition. Also, weighting
coefficients according to the temperature were also
5 experimentally obtained and converted values. As the
bubble removing means, either the suction means of this
embodiment or a compression means may be employed.
Furthermore, after the ink in the ink channel are
intentionally removed, the suction means may be
10 operated.

As has been described above in the first
embodiment, a future ink temperature can be easily
predicted. Therefore, optimal control may be set using
"ink evaporation characteristics" and "growth of a
15 bubble in the ink channel" in consideration of a future
ejection condition in presumption or prediction of the
"ink evaporation characteristics" and the "growth of a
bubble in the ink channel".

Note that in the second to sixth embodiments, the
20 ejection quantity control described in the first
embodiment may or may not be executed in combination.
When no ejection quantity control is performed, steps
associated with the PWM control and sub-heater control
can be omitted.

25 In this embodiment, the energization time is used
as an index of energy to be supplied to the head.
However, the present invention is not limited to this.

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1 For example, when no PWM control is performed, or when
high-precision temperature prediction is not required,
the number of print dots may be used. Furthermore,
when the print duty does not suffer from a large drift,
5 the print time and the non-print time may be used.
(Seventh Embodiment)

This embodiment exemplifies an example of an ink
jet recording apparatus comprising a temperature
keeping means constituted by a self temperature control
10 type heating member, thermally coupled to a recording
head, for maintaining the temperature of the recording
head at a predetermined keeping temperature higher than
a surrounding temperature capable of performing
recording, and a temperature keeping timer for managing
15 an operation time of the heating member, a temperature
prediction means for predicting a change in ink
temperature in an ejection unit in a recording mode
prior to recording on the basis of a temperature
detected by a temperature detection member provided to
20 the recording head and of recording data, and an
ejection stabilization means for stabilizing ejection
according to the ink temperature in the ejection unit.

In this embodiment, a difference from the ink jet
recording apparatuses described in the first to sixth
25 embodiments is that the heating member provided to the
recording head is a self temperature control type
heater which contacts not a heater board but an

1 aluminum base plate as the base member of the recording
head. The self temperature control type heater
spontaneously suppresses heat generation without using
a special temperature detection mechanism when a
5 predetermined temperature is reached. For example, the
self temperature control type heater is formed of a
material such as barium titanate of PTC characteristics
(having a positive resistance temperature coefficient).
Some heaters can obtain the same characteristics as
10 described above by modifying an arrangement even when a
heater element itself has no PTC characteristics. For
example, a heater element is formed of a material
prepared by dispersing, e.g., conductive graphite
particles in a heat-resistant resin having an
15 electrical insulating property. When this element is
heated, the resin is expanded, and graphite particles
are separated from each other, thus increasing the
resistance. In such a self temperature control type
heater, a desired control temperature can be set by
20 adjusting the composition or arrangement. In this
embodiment, a heater exhibiting a control temperature
of about 36°C was used.

In this embodiment, since the temperature of the
recording head including the ink in the ejection unit
25 at the beginning of recording is basically equal to the
control temperature of the self temperature control
type heater, the ink temperature drift in the ejection

1 unit in the recording mode can be predicted on the
basis of expected energy to be supplied to the ejection
heaters in the recording mode at that control
temperature and of the thermal time constant of the
5 recording head including the ink in the ejection unit.

In ink temperature prediction of the present
invention, a temperature rise from the keeping
temperature is calculated on the basis of energy to be
supplied for ejection. For this reason, the predicted
10 ink temperature upon ejection has higher precision than
that of the temperature detected by the temperature
detection member provided to the recording head.
However, the predicted ink temperature inevitably
varies due to a difference in thermal time constant of
15 each recording head, a difference in thermal efficiency
upon ejection, and the like.

Thus, in this embodiment, the predicted ink
temperature is corrected. The predicted ink
temperature correction in this embodiment is performed
20 using the temperature detected by the temperature
detection member prepared for the recording head in the
ink jet recording apparatus of the present invention in
a state wherein the recording head is not driven. The
descent temperature table used for predicting the ink
25 temperature is corrected so as to decrease a difference
between a difference between the temperatures detected
by the temperature detection member in thermally static

1 non-ejection states before and after recording, and the
predicted ink temperature rise calculated from energy
to be supplied for ejection. In this embodiment, the
descent temperature table is corrected in such a manner
5 that error rates in units of recording lines are
sequentially accumulated, and an average value of the
error rates for one page is calculated.

Therefore, when the recording head is exchanged,
or when the surrounding temperature considerably
10 drifts, the ink temperature can be stably predicted as
compared to the above embodiments. More specifically,
in this embodiment, since the temperature detection
member of the recording head is used not only in
detection of the ink temperature at the beginning of
15 recording but also in correction of the predicted ink
temperature, the ink temperature in the ejection unit
in the recording mode can be predicted with high
precision, and ejection can be stabilized.

In this embodiment, since the aluminum base plate
20 having a heat capacity which largely influences the ink
temperature in the ejection unit is always maintained
at the control temperature, as for an increase/decrease
in ink temperature, the temperature rise caused by heat
generation of the ejection heaters, and heat radiation
25 according to the thermal time constant of the recording
head need only be predicted with reference to the
control temperature. For this reason, the ink

1 temperature can be stably predicted as compared to the
above embodiments wherein the temperature near the
ejection unit of the recording head is maintained.

In this embodiment, a recording operation is
5 inhibited or an alarm is generated for a user until the
temperature keeping timer measures a predetermined
period of time. Then, recording is performed after the
temperature keeping operation by the self temperature
control type heater is completed. For this reason, ink
10 temperature prediction can be simplified since control
can be made under an assumption that the temperature of
the aluminum base plate associated with heat radiation
is maintained at the keeping temperature as the control
temperature of the element. However, when the ink
15 temperature at the beginning of the temperature keeping
operation is detected by the temperature detection
member, and is set as an initial temperature of the
aluminum base plate, the temperature of the aluminum
base plate can be predicted at a desired timing even
20 before completion of the temperature keeping operation
as long as the temperature rise characteristics of the
self temperature control type heater are measured in
advance. Thus, the ink temperature in the ejection
unit may be predicted with reference to the initial
25 temperature so as to allow recording before completion
of the temperature keeping operation. Similarly, since
a time until completion of the temperature keeping

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1 operation can be calculated and predicted, the time of
the temperature keeping timer may be changed according
to the predicted time.

According to the temperature control method of
5 this embodiment, the same ejection stabilization
control described in the second to sixth embodiments
can be realized, and simplified temperature prediction
can be expected.

As described above, according to the present
10 invention, the temperature of the recording head is
maintained at a temperature higher than the surrounding
temperature, and ejection is stabilized according to
the ink temperature in the ejection unit, which is
presumed prior to recording on the basis of the
15 temperature detected by the temperature detection
member provided to the recording head and recording
data. Therefore, the ejection quantity and ejection
can be stabilized without considerably decreasing the
recording speed, and a high-quality image having a
20 uniform density can be obtained.

(Eighth Embodiment)

An embodiment for performing temperature
prediction different from those in the above-mentioned
first to seventh embodiments will be described in
25 detail below with reference to the accompanying
drawings. The control arrangement of this embodiment
is as shown in Fig. 16, and is substantially the same

1 as that shown in Fig. 5, except that the temperature
sensors 8e are omitted from the arrangement shown in
Fig. 5. Although not shown, a recording head has
substantially the same arrangement as that shown in
5 Fig. 6, except that the temperature sensors 8e are
omitted from the arrangement shown in Fig. 6.

(Summary of Temperature Prediction)

In this embodiment, upon execution of recording by
ejecting ink droplets from the recording head, a
10 surrounding temperature sensor for measuring the
surrounding temperature is provided to an apparatus
main body, and the ink temperature drift in an ejection
unit is presumed and predicted as a change in ink
temperature from the past to the present and future by
15 calculation processing based on ink ejection energy
and energy to be supplied to sub-heaters for
maintaining the temperature of the recording head,
thereby stabilizing ejection according to the ink
temperature. More specifically, a temperature
20 detection member (the temperature sensors 8e in Figs. 5
and 6) for directly detecting the temperature of the
recording head can be omitted. It is difficult in
terms of cost to equip the temperature detection member
for directly detecting the temperature of the recording
25 head in the ink jet recording apparatus using the IJC
like in this embodiment. In addition, a countermeasure
against static electricity required for joint points

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1 between a temperature measurement circuit and the IJC
relatively complicates the recording apparatus. From
these viewpoints, this embodiment is advantageous.
Note that the recording head shown in Fig. 5 may be
5 used. In this case, the temperature sensors 8e are not
used.

Briefly speaking, in this embodiment, a change in
ink temperature in the ejection unit is presumed and
predicted by evaluating the thermal time constant of
10 the recording head and the ejection unit including the
ink, and input energy in a range from the past to
future, which energy is substantially associated with
the ink temperature using a temperature change table
calculated in advance. Based on the predicted ink
15 temperature, the head is controlled by a divided pulse
width modulation (PWM) method of heaters (sub-heaters)
for increasing the temperature of the head, and
ejection heaters.

(Temperature Prediction Control)

20 An operation executed when recording is performed
using the recording apparatus with the above
arrangement will be described below with reference to
the flow charts shown in Figs. 17 to 19.

When the power switch is turned on in step S100,
25 an internal temperature increase correction timer is
reset/set (S110). The temperature of a temperature
sensor (to be referred to as a reference thermistor

1 hereinafter) on a main body printed circuit board (to
 be referred to as a PCB hereinafter) is read (S120) to
 detect the surrounding temperature. However, the
 reference thermistor is influenced by a heat generation
 5 element (e.g., a driver) on the PCB, and cannot often
 detect the accurate surrounding temperature of the
 head. Therefore, the detection value is corrected
 according to an elapse time from the ON operation of
 the power switch of the main body, thereby obtaining
 10 the surrounding temperature. More specifically, the
 elapse time from the ON operation of the power switch
 is read from the internal temperature increase
 correction timer to look up an internal temperature
 increase correction table (Table 5) so as to obtain the
 15 accurate surrounding temperature from which the
 influence of the heat generation element is corrected
 (S140).

Table 5

20	Internal Temperature Increase Correction Timer (min)	Correction Value (°C)
	0 to 2	0
	2 to 5	-2
	5 to 15	-4
25	15 to 30	-6
	more than 30	-7

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1 In step S150, a temperature prediction table
(Fig. 20) is looked up to predict a current head chip
temperature (β), and the control waits for an input
print signal. The current head chip temperature (β) is
5 predicted by updating the surrounding temperature
obtained in step S140 by adding to it a value
determined by a matrix of a difference between the head
temperature and the surrounding temperature with
respect to energy to be supplied to the head in unit
10 time (power ratio). Immediately after the power switch
is ON, since there is no print signal (energy to be
supplied to the head is 0), and the temperature
difference between the head temperature and the
surrounding temperature is also 0, a matrix value "0"
15 (thermal equilibrium) is added. If there is no input
print signal, the flow returns to step S120, and the
processing is repeated from the operation for reading
the temperature of the reference thermistor. In this
embodiment, a head chip temperature prediction cycle is
20 set to be 0.1 sec.

 The temperature prediction table shown in Fig. 20
is a matrix table showing temperature increase
characteristics in unit time, which are determined by
the thermal time constant of the head and energy
25 supplied to the head. As the power ratio becomes
larger, the matrix value is also increased. On the
other hand, when the temperature difference between the

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1 head temperature and the surrounding temperature
becomes larger, the thermal equilibrium tends to be
established. For this reason, the matrix value is
decreased. The thermal equilibrium is established when
5 the supplied energy is equal to radiation energy. In
the table, the power ratio = 500% means that energy
obtained when the sub-heaters are energized is
converted into the power ratio.

The matrix values are accumulated based on this
10 table every time the unit time elapses, so that the
temperature of the head at that time can be presumed,
and a future change in temperature of the head can be
predicted by inputting future print data, or energy to
be supplied to the head (e.g., to the sub-heaters) in
15 the future.

When the print signal is input, a target (driving)
temperature table (Table 6) is looked up to obtain a
print target temperature (α) of the head chip capable
of performing optimal driving at the current
20 surrounding temperature (S170). In Table 6, the reason
why the target temperature varies depending on the
surrounding temperature is that even when the
temperature on a silicon heater board of the head is
controlled to be a predetermined temperature, since the
25 ink flowing into the heater board has a low temperature
and a large thermal time constant, the temperature of a
system around the head chip is lowered from the

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1 viewpoint of an average temperature. For this reason,
 as the surrounding temperature becomes lower, the
 target temperature of the silicon heater board of the
 head must be increased. Therefore, the above-mentioned
 5 keeping temperature can be attained in a
 low-temperature environment by changing the target
 temperature in control.

Table 6

10	Surrounding Temperature (°C)	Target Temperature (°C)
	up to 12	52
	12 to 15	50
	15 to 18	48
15	18 to 21	46
	21 to 24	44
	24 to 27	42
	27 to 30	40
	30 to 33	38
20	33 to 36	36

In step S180, a difference γ ($= \alpha - \beta$) between the
 print target temperature (α) and the current head chip
 temperature (β) is calculated. In step S190, a
 sub-heater control table (Table 7) is looked up to
 25 obtain a pre-print sub-heater ON time (t) for the
 purpose of decreasing the difference (γ). This
 function is to increase the temperature of the entire

1 head chip using the sub-heaters when the presumed head
 temperature and the target temperature have a
 difference therebetween at the beginning of the print
 operation. With this function, the temperature of the
 5 entire head chip including the ink in the ejection unit
 can approach the target temperature as much as
 possible.

Table 7

10	Difference γ ($^{\circ}\text{C}$)	Sub-heater ON Time (sec)	γ ($^{\circ}\text{C}$)	ON (sec)
	-18 to -15	6	-42 to -39	14
	-15 to -12	5	-39 to -36	13
	-12 to -9	4	-36 to -33	12
15	-9 to -6	3	-33 to -30	11
	-6 to -5	2	-30 to -27	10
	-5 to -4	1	-27 to -24	9
	-4 to -3	0.5	-24 to -21	8
	-3 to -2	0.2	-21 to -18	7
20	more than -2	0		

After the pre-print sub-heater ON time (t) is
 obtained, the temperature prediction table (Fig. 20) is
 looked up to predict a (future) head chip temperature
 25 immediately before the start of the print operation
 under an assumption that the sub-heaters are turned on
 for the setting time (S200). The difference (γ)

1 between the print target temperature (α) and this head
chip temperature (β) is calculated (S210). Since the
difference between the print target temperature and the
head chip temperature can be considered as a difference
5 between the keeping temperature and the ink
temperature, the ink temperature can be substantially
obtained as a sum the keeping temperature and the
difference (γ) (S220). Needless to say, it is
preferable that the difference (γ) is 0. When the
10 driving operation is performed according the predicted
ink temperature with reference to the ejection unit ink
temperature - pre-pulse table shown in Fig. 12A so as
to attain the ejection quantity equal to that obtained
by the print operation at the keeping temperature, the
15 ejection quantity can be stabilized.

This embodiment is attained under an assumption
that the ink temperature is set to be at least equal to
or higher than the keeping temperature before printing
using the above-mentioned sub-heaters, and employs a
20 method for correcting an increase in ejection quantity
when the recording head accumulates heat in a
continuous print operation at a high duty, and the ink
temperature is increased accordingly. In this
embodiment, the ejection quantity based on a difference
25 from the target value is corrected by a PWM method.

The chip temperature of the head changes depending
on its ejection duty during a one-line print operation.

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1 More specifically, since the difference (γ) is
sometimes changed in one line, it is preferable to
optimize the pre-pulse value in one line according to
the change in difference. In this embodiment, the
5 one-line print operation requires 1.0 sec. Since the
temperature prediction cycle of the head chip is also
0.1 sec, one line is divided into 10 areas in this
embodiment. The pre-pulse value (S230) at the
beginning of printing, which value is set previously,
10 is a pre-pulse value at the beginning of printing of
the first area.

A method of determining a pre-pulse value at the
beginning of printing of each of the second to 10th
areas will be described below. In step S240, $n = 1$ is
15 set, and in step S250, n is incremented. In this case,
 n represents the area, and since there are 10 areas,
the control escapes from the following loop when n
exceeds 10 (S260).

In the first round of the loop, the pre-pulse
20 value at the beginning of printing of the second area
is set. More specifically, the power ratio of the
first area is calculated based on the number of dots
and the PWM value of the first area (S270). The power
ratio corresponds to a value plotted along the ordinate
25 when the temperature prediction table is looked up.
The reason why the number of dots (print duty) is not
merely used is that energy to be supplied to the head

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1 chip varies depending on the pre-pulse value even if
the number of dots remains the same. Using the concept
of the "power ratio", a single table can be used even
when the PWM control is performed or when the
5 sub-heaters are ON.

In this case, the head chip temperature (β) at the
end of printing of the first area (i.e., at the
beginning of printing of the second area) is predicted
by substituting the power ratio in the temperature
10 prediction table (Fig. 20) (i.e., by looking up the
table) (S280). In step S290, the difference (γ)
between the print target temperature (α) and the head
chip temperature (β) is calculated again. A pre-pulse
value for printing the second area is obtained by
15 looking up Fig. 12A based on the difference (γ), and is
set on a memory (S300 and S310).

Thereafter, the power ratio in the corresponding
area is sequentially calculated based on the number of
dots and the pre-pulse value of the immediately
20 preceding area, and the head chip temperature (β) at
the end of printing of the corresponding area is
predicted. Then, the pre-pulse value of the next area
is set based on the difference (γ) between the print
target temperature (α) and the head chip temperature
25 (β) (S250 to S310). After the pre-pulse values of all
the 10 areas in one line are set, the flow advances
from step S260 to step S320 to heat the sub-heaters

1 before printing. Thereafter, a one-line print
operation is performed according to the set pre-pulse
values (S330). Upon completion of the one-line print
operation in step S330, the flow returns to step S120
5 to read the temperature of the reference thermistor.
Thereafter, the above-mentioned control is repeated in
turn.

With the above-mentioned control, the actual
ejection quantity can be stably controlled
10 independently of the ink temperature, and a
high-quality recorded image having a uniform density
can be obtained.

The ejection quantity control will be described
below again. In this embodiment, ejection/ejection
15 quantity of the head is stabilized by controlling the
following two points.

① The target temperature is determined from the
"target temperature table" according to the surrounding
temperature, so that the temperature of the recording
20 head including the ink in the ejection unit reaches at
least the keeping temperature, and the recording head
is heated using the sub-heaters as needed. More
specifically, in this embodiment, the ink temperature
in the ejection unit is equal to a temperature obtained
25 by subtracting the difference between the target
temperature and the surrounding temperature from a
calculated temperature.

1 ② A shift (difference) between the target
temperature and the current head temperature is
presumed. The sum of the keeping temperature and the
presumed difference is considered as the ink
5 temperature in the ejection unit, and the pre-pulse
value is set according to the ink temperature, thereby
stabilizing the ejection quantity.

In this embodiment, since a future head
temperature can be predicted without using a
10 temperature sensor for directly measuring the
temperature of the recording head, various head control
operations can be performed before the actual print
operation, and hence, recording can be performed more
properly.

15 Constants such as the number of divided areas (10
areas) in one line, the temperature prediction cycle
(0.1 sec), and the like used in this embodiment are
merely examples, and the present invention is not
limited to these.

20 (Ninth Embodiment)

In this embodiment, the current head temperature
is presumed from a print duty like in the eighth
embodiment, and a suction condition is changed
according to the presumed head temperature. The
25 suction condition is controlled based on a suction
pressure (initial piston position) or a suction
quantity (volume change quantity or vacuum hold time).

1 Fig. 21 shows the head temperature dependency of the
vacuum hold time and the suction quantity. Although
the suction quantity can be controlled according to the
vacuum hold time for a predetermined period, the
5 suction quantity changes independently of the vacuum
hold time in other periods. Since the suction quantity
is influenced by the head temperature presumed from the
print duty, the vacuum hold time is changed according
to the presumed head temperature. In this manner, even
10 when the head temperature changes, the ejection
quantity can be maintained constant (optimal quantity),
thus stabilizing ejection.

Furthermore, when a plurality of heads are used,
the head temperature is presumed more precisely by
15 performing heat radiation correction according to the
arrangement of the heads. Since the end portion of a
carriage causes heat radiation more easier than the
central portion, and the temperature distribution
varies, ejection largely influenced by the temperature
20 also varies. For this reason, correction is made while
heat radiation at the end portion is assumed to be
100%, and heat radiation at the central portion is
assumed to be 95%. With this correction, a thermal
variation can be prevented, and stable ejection can be
25 attained. Furthermore, the suction condition may be
changed according to the features or states of heads in
units of heads.

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1 Furthermore, in this embodiment, a head
temperature drop upon suction is presumed. When the
surrounding temperature and the head temperature have a
difference therebetween, the ink at a high temperature
5 is discharged by suction, and a new ink at a low
temperature is supplied from the ink tank. The head at
a high temperature is cooled by the supplied new ink.
Table 8 below shows the difference between the
surrounding temperature and the presumed head
10 temperature, and temperature drop correction upon
suction. When the head temperature is presumed from
the print duty, the temperature drop upon suction can
be corrected based on the difference between the
surrounding temperature and the head temperature, and
15 the head temperature after suction can be
simultaneously predicted.

Table 8

20	Difference between Surrounding Temperature and Presumed Head Temperature (°C)	ΔT Upon Suction (°C)
	0 to 10	-1.2
	10 to 20	-3.6
	20 to 30	-6.0

25 In the case of an exchangeable head, the
temperature of the ink tank need be presumed. Since
the ink tank is in tight contact with the head, the
temperature rise caused ejection influences the ink

1 tank. For this reason, the ink tank temperature is
presumed from an average of temperatures for last 10
minutes. The presumed temperature can be fed back to
compensate for the temperature drop upon suction.

5 In the case of a permanent head, since the head
and the ink tank are separated from each other, the
temperature of an ink to be supplied is equal to the
surrounding temperature, and the temperature of the ink
tank need not be predicted.

10 Furthermore, in the case of a sub-tank system
shown in Fig. 22, even when the suction operation is
performed while the temperature of the ink is high, the
suction quantity is undesirably increased. For this
reason, an ink-level pull-up effect cannot be expected,
15 thus causing an ink supply error. When the head
temperature predicted from the print duty is high, the
number of times of suction is increased to obtain the
sufficient ink-level pull-up effect. Table 9 below
shows the relationship between the difference between
20 the surrounding temperature and the presumed head
temperature, and the number of times of suction. In
Table 9, as the difference between the surrounding
temperature and the presumed head temperature is
larger, the number of times of suction is increased.
25 Thus, the ink-level pull-up effect can be prevented
from being impaired.

1 Note that the sub-tank system shown in Fig. 22
includes a main tank 41 provided to the apparatus main
body, a sub-tank 43 arranged on, e.g., a carriage, a
head chip 45, a cap 47 for covering the head chip 45,
5 and a pump 49 for applying a suction force to the cap
47.

Table 9

10	Difference between Surrounding Temperature and Presumed Head Temperature (°C)	Number of Times of Suction
	0 to 10	8
	10 to 20	10
	20 to 30	12

(10th Embodiment)

15 The current head temperature is presumed from the
print duty like in the ninth embodiment. In this
embodiment, a pre-ejection condition is changed
according to the presumed head temperature, and this
embodiment corresponds to the second embodiment.

20 At a high temperature, the ink in the ejection
unit is easily evaporated. Thus, the pre-ejection
interval or the number of times of pre-ejection can be
changed according to the presumed head temperature. In
this embodiment, the number of times of pre-ejection is
25 changed according to the presumed head temperature upon
pre-ejection like in Table 1. At the same time, as the
temperature becomes higher, the ejection quantity is

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1 increased. Thus, the pulse width is decreased to
 suppress the ejection quantity. Since this embodiment
 is substantially the same as the second embodiment
 except for the above-mentioned point, a detailed
5 description thereof will be omitted.

10

15

20

25

1 (11th Embodiment)

2 This embodiment exemplifies a case wherein the
3 past average head temperature within a predetermined
4 period is presumed from a temperature detected by a
5 reference temperature sensor provided to a main body,
6 and a print duty, and a predetermined recovery means is
7 operated at intervals optimally set according to the
8 average head temperature. The recovery means to be
9 controlled according to the average head temperature in
10 this embodiment includes pre-ejection and wiping means,
11 which are executed at predetermined time intervals
12 during printing (in a cap open state) so as to
13 stabilize ejection. As is known in the ink jet
14 technique, the pre-ejection means is executed for the
15 purpose of preventing a non-ejection state or a change
16 in density caused by evaporation of the ink from nozzle
17 openings. Paying attention to the fact that ink
18 evaporation varies depending on the head temperature,
19 in this embodiment, the optimal pre-ejection interval
20 and the optimal number of times of pre-ejection are set
21 according to the average head temperature, and
22 pre-ejection operations are performed efficiently in
23 terms of time or ink consumption.

24 In open-loop temperature control, i.e., in a
25 method of calculating and presuming a temperature at
26 that time on the basis of the temperature detected by
27 the reference temperature sensor provided to the main

1 body, and the past print duty, as the major
constituting element of this embodiment, the average
head temperature during the past predetermined period,
which is required in this embodiment, can be easily
5 obtained. This embodiment pays attention to the fact
that ink evaporation is associated with the head
temperatures at respective times, and the total
quantity of evaporated ink during a predetermined
period has a strong correlation with the average head
10 temperature during this period.

Also, in this embodiment, paying attention to the
fact that the wet quantity due to, e.g., the ink varies
depending on the head temperature, and evaporation of
the wet which makes it difficult to remove the ink or
15 the foreign matter, is associated with the head
temperature (the temperature of the orifice formation
surface), the wiping operation is efficiently performed
by setting optimal wiping intervals according to the
past average head temperature. Since the wet quantity
20 or evaporation of the wet associated with wiping has a
stronger correlation with the past average head
temperature than the head temperature at the time of
wiping, a head temperature presuming means of this
embodiment is suitably used.

25 The outline of the print sequence of this
embodiment is the same as that shown in the flow chart
of Fig. 15 described in the third embodiment. In this

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1 embodiment, in step S2, a pre-ejection timer is set
according to the average head temperature at that time,
and is started. Furthermore, in step S3, a wiping
timer is set according to the average head temperature
5 at that time, and is started.

When a print operation is to be continued, the
wiping timer and the pre-ejection timer, which have
been set according to the average head temperature, are
checked and re-set, and after wiping or pre-ejection is
10 performed as needed, the timers are restarted (steps
S15 and S16). At this time, in steps S151 and S161,
the average head temperature is calculated regardless
of the presence/absence of execution of the operation.

More specifically, in this embodiment, since the
15 wiping and pre-ejection timings can be finely re-set
according to a change in average head temperature in
units of print lines, optimal wiping and pre-ejections
according to the evaporation and wet conditions of the
ink can be performed.

20 Table 2 presented previously can be
employed as a correspondence table between the
pre-ejection interval and the number of times of
pre-ejection according to the average head temperature
for last 12 sec, and a correspondence table of the
25 wiping interval according to the average head
temperature for last 48 sec in this embodiment.

1 As has been described above in the sixth
embodiment, the head temperature is not limited to a
presumed temperature at the present time, and a future
head temperature can also be easily predicted.
5 Therefore, the optimal pre-ejection interval and the
optimal number of times of pre-ejection may be set in
consideration of a future condition.

(12th Embodiment)

 This embodiment exemplifies a suction recovery
10 means according to the past average head temperature
for a relatively long period of time as another example
of recovery control based on the presumed average head
temperature like in the 11th embodiment. In this
embodiment, as shown in Table 2 (fourth embodiment)
15 above, the suction recovery interval is set according
to the average head temperature for last 12 hours, and
a suction recovery operation is frequently performed as
the average head temperature is higher. The average
temperature may be re-set for, e.g., every page.

20 When the past average head temperature over a
relatively long period of time is to be presumed using
a plurality of heads, as shown in Fig. 4 presented
previously, after the plurality of heads are thermally
coupled, the average head temperature may be presumed
25 on the basis of the average duty of the plurality of
heads, and the temperature detected by the reference
temperature sensor, so that control may be simplified

1 under an assumption that the plurality of heads are
almost identical.

As has been described above in the eighth
embodiment, the head temperature is not limited to a
5 presumed temperature at the present time, and a future
head temperature can also be easily predicted.
Therefore, optimal suction recovery control may be set
in consideration of a future condition.

For example, even when anxiety for an ejection
10 error upon execution of a high-duty print operation at
the current presumed head temperature is present, if it
is known that no high-duty print operation will be
performed in the future, the suction operation is
postponed at the present time, and is performed after a
15 recording medium is discharged, thereby shortening the
total print time.

(13th Embodiment)

This embodiment exemplifies a case wherein a
recovery system is controlled according to the history
20 of a temperature presumed from a temperature detected
by a reference temperature sensor of a main body, and a
print duty. This embodiment corresponds to the fifth
embodiment described above.

In this embodiment, a rubbing mode is controlled
25 according to the number of times of ejection according
to the head temperature, and Table 3 can be employed.

1 As has been described above in the eighth
embodiment, the head temperature is not limited to a
presumed temperature at the present time, and a future
head temperature can also be easily predicted.

5 Therefore, optimal control may be set using the
"weighted number of times of ejection" in consideration
of a future condition in the calculation of the
"weighted number of times of ejection".
(14th Embodiment)

10 This embodiment exemplifies suction recovery
control like in the fourth embodiment. In this
embodiment, in addition to presumption of a bubble
(non-print bubble) grown when the ink is left as it is,
a bubble (print bubble) grown in the print mode is also
15 presumed, thus allowing presumption of bubbles in the
ink channel with high precision. This embodiment
corresponds to the sixth embodiment described above.
In this embodiment, the non-print time and the number
of times of ejection, which are weighted by the head
20 temperature need only be counted, and this embodiment
employs Table 4 above.

 As has been described above in the eighth
embodiment, the head temperature is not limited to a
presumed temperature at the present time, and a future
25 head temperature can also be easily predicted.
Therefore, optimal control may be set using
"evaporation characteristics of the ink" and "growth of

1 bubble in the ink channel" in consideration of a future
condition in presumption and prediction of the
"evaporation characteristics of the ink" and the
"growth of bubble in the ink channel".

5 Note that in the ninth to 14th embodiments, the
ejection quantity control described in the first
embodiment may or may not be executed in combination.
When no ejection quantity control is performed, steps
associated with the PWM control and sub-heater control
10 can be omitted.

(15th Embodiment)

This embodiment exemplifies an ink jet recording
apparatus comprising a temperature keeping means
constituted by a self temperature control type heating
15 member, thermally coupled to a recording head, for
maintaining the temperature of the recording head at a
predetermined keeping temperature higher than a
surrounding temperature capable of performing
recording, and a temperature keeping timer for managing
20 an operation time of the heating member, a temperature
prediction means for predicting a change in ink
temperature in an ejection unit in a recording mode
prior to recording, and an ejection stabilization means
for stabilizing ejection according to the ink
25 temperature in the ejection unit.

In this embodiment, a difference from the ink jet
recording apparatuses described in the eighth to 14th

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1 embodiments is that the heating member provided to the
recording head is a self temperature control type
heater which contacts not a heater board but an
aluminum base plate as the base member of the recording
5 head.

Therefore, ink temperature prediction can be
simplified as compared to the above embodiments. More
specifically, in the arrangement of the recording head
like in this embodiment, since the aluminum base plate
10 having a heat capacity which largely influences the ink
temperature in the ejection unit is always maintained
at the control temperature, as for an increase/decrease
in ink temperature, the temperature rise caused by heat
generation of the ejection heaters, and heat radiation
15 according to the thermal time constant of the recording
head need only be predicted with reference to the
control temperature.

In this embodiment, a sum of a reference
temperature (keeping temperature) and a value obtained
20 by accumulating increased temperature remainders in all
the effective reference time periods (the increased
temperature remainder is not 0) before an objective
reference time period in which the ink temperature is
presumed is determined as the ink temperature during
25 the objective reference time period with reference to a
descent temperature table in Fig. 13, which shows
increased temperature remainders from the keeping

1 temperature according to the power ratio during a given
reference time period in units of elapse times from the
reference time period. A print time for one line is
assumed to be 0.7 sec, and a time period (0.02 sec)
5 obtained by dividing this print time by 35 is defined
as the reference time period.

For example, if recording is performed for the
first time at a power ratio of 20% during the first
reference time period, 80% during the second reference
10 time period, and 50% during the third reference time
period after the temperature keeping operation is
completed, the ink temperature of the ejection unit
during the fourth reference time period can be presumed
from the increased temperature remainders of the three
15 reference time periods so far. More specifically, the
increased temperature remainder during the first
reference time period is 85×10^{-3} deg (Ⓐ in Fig. 13)
since the power ratio is 20% and the elapse time is
0.06 sec; the increased temperature remainder during
20 the second reference time period is 369×10^{-3} deg (Ⓑ in
Fig. 13) since the power ratio is 80% and the elapse
time is 0.04 sec; and the increased temperature
remainder during the third reference time period is 250
 $\times 10^{-3}$ deg (Ⓒ in Fig. 13) since the power ratio is 50%
25 and the elapse time is 0.02 sec. Therefore, when these
remainders are accumulated, we have 704×10^{-3} deg, and
36.704°C as the sum of this value and 36°C are

1 predicted as the ink temperature of the ejection unit
during the fourth reference time period.

In this embodiment, ejection quantity control
based on the predicted ink temperature described in the
5 eighth embodiment can be performed.

In this embodiment, a recording operation is
inhibited or an alarm is generated for a user until the
temperature keeping timer measures a predetermined
period of time. When a surrounding temperature
10 detection means for detecting the surrounding
temperature is added like in the above embodiment, the
temperature of the aluminum base plate can be predicted
at a desired timing even before completion of the
temperature keeping operation. For this reason, the
15 ink temperature in the ejection unit may be detected
using the predicted temperature as a reference
temperature so as to allow recording before completion
of the temperature keeping operation. When the
surrounding temperature detection means is arranged,
20 since a time until completion of the temperature
keeping operation can be calculated and predicted, the
time of the temperature keeping timer may be changed
according to the predicted time.

According to the temperature control method of
25 this embodiment, the same ejection stabilization
control described in the ninth to 14th embodiments can

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1 be realized, and simplified temperature prediction can
be expected.

As described above, according to the present
invention, the temperature of the recording head is
5 maintained at a temperature higher than the surrounding
temperature, and ejection is stabilized according to
the ink temperature in the ejection unit, which is
presumed prior to recording. Therefore, the ejection
quantity and ejection can be stabilized without
10 considerably decreasing the recording speed, and a
high-quality image having a uniform density can be
obtained.

When the ink temperature is presumed without
arranging temperature sensors in the recording head,
15 the recording apparatus main body and the recording
head can be simplified.

(16th Embodiment)

The 16th embodiment of the present invention will
be described in detail below with reference to the
20 accompanying drawings. In this embodiment, a
temperature detection member capable of directly
detecting the temperature of the recording head of the
above-mentioned recording apparatus, and a temperature
calculation circuit for this member are added.

25 The control arrangement of this embodiment is the
same as that shown in Fig. 5, and the arrangement of a
recording head is the same as that shown in Fig. 6. In

1 Fig. 6, head temperature sensors 8e are arranged on a
heater board 853 of the recording head together with
ejection heaters 8g and sub-heaters 8d, and are
thermally coupled to the heat source of the recording
5 head. In this embodiment, the output temperature
characteristics of a temperature detection diode, which
is formed simultaneously with a diode formed on the
heater board as a portion of an ejection heater driver,
are used as a temperature sensor (Di sensor).

10 Fig. 23 shows temperature characteristics of the
temperature characteristics of the temperature
detection member of the recording head of this
embodiment. In this embodiment, the temperature
detection member is driven at a constant current of 200
15 μA , and exhibits output characteristics, i.e., an
output voltage V_f of $575 \pm 25 \text{ mV}$ (25°C), and the
temperature dependency of about $-2.5 \text{ mV}/^\circ\text{C}$. Although
variations in temperature dependency are small in terms
of the manufacturing process of the element, the output
20 voltage deviates largely, and a variation of about 25°C
may occur. The temperature detection precision
required in this embodiment is $\pm 2^\circ\text{C}$, and 12 ranks of
identification information are required so as to
measure a correction value and to provide information
25 to the recording head upon delivery of the recording
head. Variations of the temperature detection elements
can be suppressed in the manufacturing process. For

1 this purpose, however, the manufacturing cost of the
recording head is undesirably increased, and it is very
disadvantageous for an exchangeable recording head like
in this embodiment.

5 In this embodiment, the temperature sensor of the
recording head is corrected using a reference sensor
provided to the recording apparatus main body. When
the detection temperature is corrected, the temperature
of the ink in a common ink chamber surrounded by a top
10 plate 8f, which temperature is important for
stabilization of ejection, especially, the ink
temperature in the ejection unit, can be detected with
high precision, and ejection can be stabilized.

(Temperature Calibration)

15 Calibration of the temperature detection member of
the recording head in this embodiment is performed
using a chip thermistor 5024 arranged on an electrical
circuit board of the main body in a non-record mode
with the small ink temperature drift in the ejection
20 unit. The chip thermistor 5024 is arranged on the
electrical circuit board together with its detection
circuit, and has already been calibrated as well as a
variation of the detection circuit before delivery of
the recording apparatus.

25 Since the chip thermistor 5024 can detect the
temperature in the recording apparatus main body, it is
considered that the temperature of the recording head

1 is equal to the detection value in a state wherein no
energy for a temperature keeping operation and ejection
is supplied to the recording head. When such energy is
supplied to the recording head, the temperature in the
5 recording apparatus main body becomes almost equal to
the temperature of the recording head after an elapse
of a predetermined period of time after the supply of
energy.

This embodiment comprises a non-record time
10 measurement timer for measuring a non-record time.
When a non-record state continues over a predetermined
period of time, the temperature detection member of the
recording head is calibrated to calculate a correction
value for matching a value actually measured by the
15 temperature detection member of the recording head with
the detection temperature of the chip thermistor of the
main body. The calculated correction value is stored
in a RAM or an EEPROM 62. Thereafter, the temperature
of the recording head is calculated by correcting the
20 actually measured value using the correction value.
The non-record time in this embodiment means a state
wherein no energy is supplied to the recording head.
Therefore, the non-record time does not include a time
while the temperature of the recording head is
25 maintained as a preliminary operation for recording.
Even in a power OFF state, when a timer means backed up

1 by a battery is available, the power OFF time may be
measured for the purpose of simplifying timer control.

Furthermore, as a calibration execution timing,
every time the non-record time exceeds a predetermined
5 period of time, calibration may be executed. When the
non-record time exceeds the predetermined period of
time, only a calibration request signal is generated,
and the calibration is not executed actually at that
time. Thereafter, the calibration may be executed
10 before new energy is supplied to the recording head,
e.g., before the beginning of the next recording or
immediately after the power switch is turned on.

The heat source in the recording apparatus
includes a power supply unit of the recording
15 apparatus, and a control element itself on the
electrical circuit board in addition to the recording
head. In some cases, the detection temperature of the
chip thermistor 5024 as the reference temperature
sensor in the main body may exceed the temperature of
20 the remaining portion in the recording apparatus
including the recording head. For this reason, in this
embodiment, the detection temperature of the chip
thermistor 5024 is corrected on the basis of the
power-ON time of the recording apparatus. As a
25 correction table for this operation, Table 5 presented
previously is used, and the same timer as that for

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1 measuring the non-record time is used for measuring the
power-ON time.

In this embodiment, the power-ON timer simply
measures a time elapsed from when the power switch is
5 turned on until the temperature sensor of the recording
head is corrected. When the influences of the heat
generation amount of the power supply and the heat
generation amount of the driver for the recording head
are large, a temperature rise calculated based on
10 energy supplied to the recording head may be corrected
in addition to the power-ON time. Furthermore,
correction may be made on the basis of all the past
factors such as the power-ON time or energy supplied to
the recording head that influence the local temperature
15 rise of the chip thermistor 5024 of the main body.

Fig. 24 shows a processing flow for calibrating
the temperature detection member of the recording head
in this embodiment. Calibration processing will be
described in detail below with reference to Fig. 24 and
20 the block diagram of Fig. 5.

When the power switch is turned on in step S400, a
CPU 60 reads a Di sensor correction value (a) stored in
the EEPROM 62 into its internal RAM so as to set a
state wherein the Di sensor is corrected and used
25 (S410). Then, the power-ON timer is reset/started to
prepare for temperature rise correction of the chip
thermistor sensor 5024 in the main body (S420). Then,

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1 the non-record timer for determining the correction
timing of the Di sensor is reset/started (S440). In
this state, the control stands by while checking if the
non-record timer reaches a time-out state (S450) or if
5 a print signal is input (S460).

When the print signal is input first, a head
heating operation is started to prepare for the print
operation (S470). In this case, temperature detection
for the head heating operation is performed by
10 correcting the temperature detected by the Di sensor
using the correction value stored in the EEPROM 62.
After the head heating operation, the recording (print)
operation is performed (S480). Thereafter, the head
heating operation is stopped (S490). During the print
15 operation, as described above, ejection stabilization
control can be performed by a PWM ejection quantity
control method based on the detection temperature of
the recording head. In the head heating operation and
the recording operation, since energy is supplied to
20 the recording head, the temperature of the recording
head is different from (normally higher than) the
temperature of the chip thermistor 5024 on the main
body electrical circuit board. For this reason, after
the recording operation is completed, the non-record
25 timer is reset/started (S440), thus re-waiting for the
correction timing of the Di sensor.

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1 When the non-record timer has reached the time-out
state in the standby state, i.e., when it is considered
that the temperature in the recording apparatus main
body (the temperature of the chip thermistor 5024)
5 becomes almost equal to the temperature of the
recording head, the Di sensor correction is performed.
In the Di sensor correction, the temperature (Tt) of
the reference thermistor (chip thermistor 5024) is read
(S500), and the temperature rise correction of the
10 temperature of the reference thermistor is performed
with reference to the data from the power-ON timer for
temperature rise correction (S510). The temperature
rise correction is performed using a correction value b
in a table (Table 5) stored in a program ROM 61 (Tt +
15 b).

 Then, the Di sensor temperature (Td) is read
(S530), and the Di sensor correction value (a) is
calculated (S540). The Di sensor correction value is
calculated as a difference (Tt + b - Td) between the
20 temperature (Tt + b) of the reference thermistor 5024
after the temperature rise correction, and the Di
sensor temperature (Td). The correction value (a)
obtained as described above of the Di sensor as the
temperature sensor of the recording head is stored in
25 the backup EEPROM, and is left in the internal RAM of
the CPU 60 for the next temperature control (S550). In
this manner, the correction of the Di sensor is

1 completed, and the flow returns to step S440 to prepare
for the next correction timing or the print operation.

As described above, since the temperature
detection member of the recording head can be easily
5 calibrated, even when an exchangeable recording head is
used like in this embodiment, the temperature control
of the recording head can be stably performed. When
control is made using the temperature detection member
of the recording head, which member is corrected easily
10 as described above, an actual ejection quantity can be
stably controlled independently of the ink temperature,
and a high-quality recorded image having a uniform
density can be obtained.

In this embodiment, when 30 minutes have elapsed
15 as the non-record time, the correction is performed.
However, this time period may be properly set according
to the required precision of calibration (correction).

In this embodiment, as an example of using the
calibrated temperature detection member of the
20 recording head, double-pulse PWM control for
controlling the ejection quantity is used. However,
single-pulse PWM control or PWM control using three or
more pulses may be used. In this embodiment, control
is made to perform optimal ejection according to the
25 temperature of the recording head. For example, this
embodiment may be used in control for changing a
recording speed or delaying (standing by) recording so

1 that the temperature of the recording head falls within
a predetermined range. The detection temperature of
the calibrated temperature detection member may be used
not only in driving control of the recording head but
5 also in control of a known recovery system as ejection
stabilization means, for example, a means for forcibly
discharging the ink from the recording head, wiping
means, and pre-ejection means.

(17th Embodiment)

10 In this embodiment, the calibration timing of a
temperature detection member (Di sensor) of a recording
head is determined by measuring the change rate of the
detection temperature of the temperature detection
member. Since the present invention is not limited to
15 the arrangement of the recording head, the arrangement
of the temperature detection member of the recording
head, and the like, the same arrangements as those in
the 16th embodiment described above are used, and only
a calibration timing determination method will be
20 described below with reference to Fig. 25. The same
reference numerals in Fig. 25 denote the same steps as
in Fig. 24.

In this embodiment, the change rate of the
detection sensor of the Di sensor is measured from a
25 timing immediately after the power switch is turned on
(S600). The change rate of the detection temperature
is measured by calculating a difference between

1 temperatures at predetermined time intervals. In this
embodiment, the detection temperature is read every
minute, and a difference between the current detection
temperature stored in the internal RAM of the CPU 60
5 and the detection temperature one minute before is
calculated as the detection temperature change rate
(α). If it is determined in step S610 that the change
rate is smaller than 0.2 deg/min, i.e., if it is
considered that the temperature in the recording
10 apparatus main body (the temperature of the chip
thermistor 5024) becomes almost equal to the
temperature of the recording head, the Di sensor of the
recording head is calibrated (S610). In this
embodiment, in order to avoid frequent calibration, the
15 presence/absence of execution of correction is checked
so that correction is performed once per power ON
operation (S620). If it is determined that the Di
sensor is corrected for the first time, calibration is
performed in the same manner as in the above
20 embodiment, and finally, a signal indicating the end of
calibration, i.e., the end of Di sensor correction is
recorded (S630).

In this embodiment, since the sensor need only be
corrected once when, e.g., the head is exchanged, it is
25 sufficient that the correction is performed at least
once after the power ON operation. For this reason,
the temperature rise correction of the reference

1 temperature sensor of the main body as a temperature
correction method after a relatively long period of
time elapses after the power ON operation described in
the above embodiment may be omitted. In this
5 embodiment, since it is considered that the recording
head is calibrated at a relatively early timing after
the power switch is turned on, when the power switch is
not so frequently turned on/off, the print operation
for several pages after the power ON operation may be
10 performed using an average value of temperature
correction pre-stored in the ROM without using a
rewritable storage element such as the EEPROM 62.

When the exchange operation of the recording head
can be detected by, e.g., detecting
15 attachment/detachment of the recording head using a
mechanical switch, if it is determined that the change
rate is smaller than a predetermined value after an
exchange signal of the recording head is input,
calibration may be performed only once.

20 In this embodiment, when the change rate is
smaller than 0.2 deg/min, the Di sensor of the recording
head is calibrated. However, the reference change rate
may be set according to the required precision of
calibration (correction).

25 (18th Embodiment)

This embodiment exemplifies a method of preventing
erroneous correction of a temperature detection member

1 of a recording head. The normal temperature cannot
often be detected due to a trouble such as
disconnection of the temperature detection member of
the recording head or an abnormality of a detection
5 circuit of the main body. In particular, in the case
of an exchangeable head, the electrical connection of
the temperature detection member may be temporarily
disabled. Also, the detection circuit may temporarily
cause an abnormality due to electrostatic noise.

10 In this embodiment, as shown in Fig. 26, when the
temporary abnormality occurs, calibration of the
temperature detection member is delayed or stopped.
The same reference symbols in Fig. 26 denote the same
steps as in Fig. 25.

15 In step S640 in Fig. 26, if the correction value
becomes equal to or larger than 10, it is determined
that the above-mentioned abnormality occurs, and the
correction value is neither stored nor updated. When
the correction value is smaller than 10, the correction
20 value is updated (S550). In this embodiment, when an
abnormal correction value is calculated, the control
waits for the next correction timing. However, an
abnormal temperature alarm may be generated to urge a
user to re-attach the recording head.

25 As described above, according to the present
invention, since the temperature detection member
provided to the recording head is easily calibrated by

1 the reference temperature sensor provided to the main
body, the temperature of the recording head, which is
important for stabilizing ejection, can be detected
with high precision, and a high-quality image can be
5 obtained.

(19th Embodiment)

Fig. 27 is an explanatory view of a temperature
calculation system for performing a temperature
calculation using a temperature calculation algorithm
10 of the present invention. In Fig. 27, an object 1 for
the temperature calculation corresponds to a recording
head in the case of a recording apparatus. The object
1 has a temperature calculation objective point 1A
where the temperature calculation is performed, and
15 corresponds to a heater surface, contacting an ink, of
the recording head in the recording apparatus. A heat
source 2 applies heat to the object 1, and a controller
5 performs the temperature calculation to control the
heat source 2.

20 The details of the temperature calculation
algorithm for calculating a change in temperature of
the temperature calculation objective point 1A of the
object 1 when the heat source 2 is turned on/off will
be described below.

25 In the present invention, the head temperature is
presumed basically using the following heat conduction
formulas:

1 •In heating:

$$\Delta\text{temp} = a\{1 - \exp[-m*T]\} \quad \dots(1)$$

•In cooling started during heating:

$$\Delta\text{temp} = a\{\exp[-m(T - T_1)] - \exp[-m*T]\} \quad \dots(2)$$

5 where temp: increased temperature of object

a: equilibrium temperature of object by
heat source

T: elapse time

m: thermal time constant of object

10 T₁: time for which heat source is removed

When the object 1 such as the recording head is processed as a lumped constant system, a change in temperature can be theoretically calculated and presumed upon combination of the above-mentioned

15 formulas (1) and (2). However, every time the heat source is turned on/off, in the case of the recording apparatus, the formulas (1) and (2) must be developed according to the print duty. In a system wherein the heat source is frequently turned on/off, it is
20 difficult to realize such presumption in terms of processing power. Therefore, in the present invention, the above-mentioned formulas are developed as follows.
<Change in temperature after elapse of nt time after heat source is ON>

$$\begin{aligned} & a\{1-\exp[-m*n*t]\} \quad \dots<1> \\ & = a\{\exp[-m*t]-\exp[-m*t]+\exp[-2*m*t]-\exp[-2*m*t]+\dots \\ & \quad +\exp[-(n-1)*m*t]-\exp[-(n-1)*m*t]+1-\exp[-n*m*t]\} \end{aligned}$$

$$\begin{aligned}
&= a\{1-\exp[-m*t]\} \\
&\quad +a\{\exp[-m*t]-\exp[-2*m*t]\} \\
&\quad +a\{\exp[-2*m*t]-\exp[-3*m*t]\} \\
&\quad \dots\dots\dots \\
&\quad +a\{\exp[-(n-1)*m*t]-\exp[-n*m*t]\} \\
&= a\{1-\exp[-mt]\} \qquad \dots<2-1> \\
&\quad +a\{\exp[-m*(2t-t)]-\exp[-m*2t]\} \qquad \dots<2-2> \\
&\quad +a\{\exp[-m*(3t-t)]-\exp[-m*3t]\} \qquad \dots<2-3> \\
&\quad \dots\dots\dots \\
&\quad +a\{\exp[-m*(nt-t)]-\exp[-m*nt]\} \qquad \dots<2-n>
\end{aligned}$$

Since the above-mentioned formulas are developed as described above, the formula <1> coincides with <2-1>+<2-2>+<2-3>+...+<2-n>.

Formula <2-n>: equal to the temperature of the object at time nt when heating is performed from time 0 to time nt, and the heat source is kept OFF from time t to time nt

Formula <2-3>: equal to the temperature of the object at time nt when heating is performed from time (n-3)t to time (n-2)t, and the heat source is kept OFF from time (n-2)t to time nt

Formula <2-2>: equal to the temperature of the object at time nt when heating is performed from time (n-2)t to time

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1 (n-1)t, and the heat source is kept
OFF from time (n-1)t to time nt

Formula <2-1>: equal to the temperature of the
object at time nt when heating is
5 performed from time (n-1)t to time
nt

The fact that the total of the above formulas are
equal to the formula <1> has the following meaning.
That is, a change in temperature (increase in
10 temperature) of the object 1 is calculated by obtaining
a decreased temperature after an elapse of unit time
from a temperature increased by energy supplied in unit
time (corresponding to each of the formulas <2-1>,
<2-2>, ..., <2-n>), and a total sum of decreased
15 temperatures at the present time from temperatures
increased in respective past unit times is calculated
to presume the current temperature of the object 1
(<2-1>+<2-2>+...+<2-n>).

An example will be described with reference to
20 Fig. 28. In Fig. 28,
Abscissa: elapse time
Ordinate: increased temperature
Curve a: temperature increase curve obtained when
the heat source 2 is driven at a duty
[X%] from time 0 to t3
25 Curve b1: temperature increase/decrease curve
obtained when the heat source 2 is

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1 driven at the duty [X%] from time 0 to
t1, and thereafter, the driving
operation is stopped

Curve b2: temperature increase/decrease curve
5 obtained when the heat source 2 is
driven at the duty [X%] from time t1 to
t2, and thereafter, the driving
operation is stopped

10 Curve b3: temperature increase curve obtained when
the heat source 2 is driven at the duty
[X%] from time t2 to t3

In this algorithm, a temperature [ta] at time t3
obtained when the heat source 2 is continuously driven
15 is calculated by [ta=tb1+tb2+tb3]. More specifically,
increased/decreased temperatures at the present time
from the temperatures increased by energy supplied in
unit time are obtained (tb1, tb2, and tb3), and a total
sum of these temperature is calculated, thus presuming
20 (calculating) the current temperature.

In this embodiment, as shown in Fig. 29, a matrix
obtained in advance by calculating changes in
temperature, i.e., increases/decreases in temperature
of the object 1 within a range of the thermal time
25 constant of the object 1 and possible input energy is
set as a table, thereby greatly decreasing the
calculation time. In this embodiment, the print duty

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1 is set at 2.5% intervals, and the unit time
(temperature presumption interval) is set to be 0.1
sec. The duty indicates the ratio of an ON time of the
head source 2 to the unit time (0.1 sec in this
5 embodiment). In the object used in this embodiment,
since a temperature increased in unit time is decreased
to almost 0°C after an elapse of 1.5 sec, the table
showing a decrease in temperature after an elapse of
1.6 sec is not provided. However, in the case of an
10 object having a thermal time constant indicating a low
thermal conductivity, a table until the increased
temperature is decreased to 0°C, and its influence is
eliminated is provided.

Control for presuming the temperature of the
15 recording head using the temperature presumption
calculation method of the present invention will be
described below with reference to the table of Fig. 30
and the flow chart of Fig. 31.

When a calculation is started, a [0.1 sec timer]
20 is set/reset in step S1000 in Fig. 31. At the same
time, the heat source ON duty for 0.1 sec is kept
monitored. In this embodiment, the average duty for
0.1 sec is calculated from a value obtained by dividing
the ON time of the heat source 2 by 0.1 sec, as
25 described above (S1010 and S1020). The current
temperature of the object (recording head) is
calculated by accumulating data on the basis of duty

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1 data (15 data) for last 1.5 sec at 0.1-sec intervals,
and the pre-set head temperature increase/decrease
table (Fig. 29) in units of duties (S1030). The flow
returns to step S1000 again to reset/set the 0.1 sec
5 timer, thus counting the number of print dots for 0.1
sec.

The temperature accumulation calculation in step
S1030 will be described below with reference to
Fig. 30. Fig. 30 shows a case wherein the duty (%)
10 changes like 100, 100, 95, and 0 at 0.1-sec intervals.

In Fig. 30(a) showing a state of an elapse time =
0.1 sec, since the duty is 100%, 15 table values at
0.1-sec intervals in the column of duty = 100 in
Fig. 29 are set in memories M1 to M15. At this time,
15 the value of the memory M1 indicates the temperature of
the object at that time, and the values in memories M2
to M15 indicate temperatures of the object at 0.1-sec
intervals. In Fig. 30(b) showing a state of an elapse
time = 0.2 sec, the values in the memories M1 to M15
20 are shifted to the left to set the temperatures of the
object at this time to be obtained by the previously
supplied energy. In addition, since the duty is 100%,
the same table values as in Fig. 30(a) are added to the
values in the memories M1 to M15. At this time, the
25 value of the memory M1 indicates the temperature of the
object at that time, and the values in memories M2 to

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1 M15 indicate temperatures of the object at 0.1-sec
intervals.

In Fig. 30(c) showing a state of an elapse time =
0.3 sec, the values in the memories M1 to M15 are
5 shifted to the left, and table values corresponding to
duty = 95 in Fig. 29 are added to the values in the
memories M1 to M15. In Fig. 30(d) showing a state of
an elapse time = 0.4 sec, the values in the memories M1
to M15 are shifted to the left, and table values
10 corresponding to duty = 0 in Fig. 29 are added to the
values in the memories M1 to M15. At this time, the
value of the memory M1 indicates the temperature of the
object at that time, and the values in memories M2 to
M15 indicate temperatures of the object at 0.1-sec
15 intervals.

As described above, in a system for applying heat
energy to an object, the temperature is calculated as
follows:

(1) a change in temperature of the object is
20 processed as a sum of discrete values per unit time;

(2) a temperature drift (change) of the object
according to each discrete value is calculated in
advance within a range of possible input energy to form
a table; and

25 (3) the table is constituted by a two-dimensional
matrix of supplied energy per unit time and elapse
time.

1 Therefore, the following effects can be expected.

1. The problem of the response time can be solved.

2. A measurement error of a temperature sensor
5 due to, e.g., electrical noise, which is very difficult to be perfectly removed, can be eliminated.

3. The problem of a direct/indirect increase in cost due to the arrangement of a temperature sensor can be eliminated.

10 In this embodiment, no temperature sensor is required, and a change in temperature of an object in the future can be predicted as long as energy to be supplied to the object in the future is known. For this reason, various control operations can be
15 performed before energy is actually applied, and more proper control can be realized. In this algorithm, the temperature calculation can be performed only by looking up the table formed by calculating a change in temperature in advance, and by adding data, resulting
20 in easy calculation control.

(20th Embodiment)

An embodiment wherein the temperature calculation algorithm of the present invention is applied to an ink jet recording apparatus will be described below.

25 The arrangement of this embodiment is the same as that shown in Figs. 1 to 3 and Fig. 16. The 20th

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1 embodiment will be described in detail below with
reference to the accompanying drawings.

(Overall Control)

5 In this embodiment, upon execution of recording by
ejecting ink droplets from a recording head, a
surrounding temperature sensor for measuring the
surrounding temperature is provided to the main body
side, and a change in temperature of the recording head
10 with respect to the surrounding temperature from the
past to the present and future is presumed by the
above-mentioned calculation processing, thereby
calculating the temperature of the recording head.
Thus, optimal temperature control and ejection control
can be performed without arranging a head temperature
15 sensor having a correlation with the head temperature.

More specifically, the head is controlled by a
divided pulse width modulation (PWM) driving method of
heaters (sub-heaters) for increasing the head
temperature, and ejection heaters on the basis of the
20 head temperature calculated by the temperature
calculation algorithm of the present invention. As one
driving method of this control, when a difference from
a temperature control target value is large, the head
temperature is increased near the target value using
25 the sub-heaters, and the remaining temperature
difference is controlled by PWM ejection quantity
control, so that a constant ejection quantity can be

1 obtained. When the PWM control as an ejection quantity
control means for a quick response head is used, a
response delay time in temperature detection due to the
position of a temperature sensor of the head or a
5 detection error due to, e.g., noise can be prevented
since calculation processing is performed, and control
that maximally utilizes this merit can be performed.
Since the PWM control in one line can be performed
without arranging the temperature sensor to the head,
10 as described above, density nonuniformity in one line
or in one page can also be eliminated.

(Temperature Calculation Control)

Briefly speaking, a change in temperature of the
head is calculated by estimating it using a matrix
15 calculated in advance within a range of the thermal
time constant of the head and possible input energy. A
detailed means for calculating and presuming a change
in temperature of the recording head uses the thermal
conduction formula (1) in heating, and uses the thermal
20 conduction formula (2) in cooling started during
heating.

In order to facilitate the calculation processing,
like in the 19th embodiment, the formulas are developed
to the formulas <2-1>, <2-2>, <2-3>, ..., <2-n>, as
25 described above. More specifically, a change in
temperature (increase in temperature) of the head is
calculated by obtaining a decreased temperature after

1 an elapse of unit time from a head temperature
increased by energy supplied in unit time
(corresponding to each of the formulas $\langle 2-1 \rangle$,
5 $\langle 2-2 \rangle$, ..., $\langle 2-n \rangle$), and a total sum of decreased
temperatures at the present time from temperatures
increased in respective past unit times is calculated
to presume the current head temperature
($\langle 2-1 \rangle + \langle 2-2 \rangle + \dots + \langle 2-n \rangle$). The calculation time of a
change in head temperature, i.e., an increase/decrease
10 in head temperature can be greatly shortened like in
the 19th embodiment since a matrix calculated in
advance within a range of the thermal time constant of
the head and possible input energy is set as a table.
In this embodiment, the print duty is set at 2.5%
15 intervals, and the unit time (temperature presumption
interval) is set to be 0.1 sec as shown in Fig. 32.

In the head used in this embodiment, since a
temperature increased in unit time is decreased to
almost 0°C after an elapse of 60.0 sec, no temperature
20 decrease table after an elapse of 60.1 sec is not
prepared. However, in the case of a head having a
thermal time constant indicating a low thermal
conductivity, a table until the increased temperature
is decreased to 0°C, and its influence is eliminated is
25 preferably prepared. Ejection quantity control is
performed by the above-mentioned PWM control.

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1 In the ink jet recording apparatus for applying
heat energy to the head as described above, in addition
to the 19th embodiment,

 (4) since the head is controlled by the divided
5 pulse width modulation (PWM) driving method of heaters
(sub-heaters) for increasing the head temperature, and
ejection heaters on the basis of the head temperature
calculated by the temperature calculation algorithm,

 4. the head temperature can be controlled, and
10 stabilization of ejection, and ejection quantity
control can be attained. Ejection control in one line
such as PWM control can be performed, and density
nonuniformity in one line or one page can be
eliminated.

15 Furthermore, in this embodiment, no temperature
sensor is required, and a change in temperature of an
object in the future can be predicted as long as energy
to be supplied to the head in the future is known. For
this reason, various control operations can be
20 performed before energy is actually applied, and more
proper control can be realized.

 In this embodiment, the time base of the table
formed by calculating in advance a change in
temperature corresponds to an arithmetic progression,
25 but need not always correspond to the arithmetic
progression. More specifically, in order to save a
memory capacity for the table, the time base of the

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1 calculation table may be roughly set for a region where
a change in temperature is small, and
increased/decreased temperature data in unit time may
be calculated and presumed from adjacent data.

5 (21st Embodiment)

An embodiment wherein the temperature calculation
algorithm of the present invention is applied to a
copying machine will be described below. Fig. 33 is a
perspective view of thermal fixing rollers of a copying
10 machine which can suitably embody or adopt the present
invention. In Fig. 33, a heat source 2 applies heat
energy to an upper fixing roller 3a, and a lower fixing
roller 3b is paired with the upper fixing roller. A
recording medium P is conveyed in a direction of an
15 arrow in Fig. 33.

In the copying machine, an electrostatic latent
image according to an original image is formed on a
transfer drum (not shown). A toner as a recording
agent is attracted to the electrostatic latent image,
20 and the toner on the transfer drum is transferred onto
the recording medium. Thereafter, the recording medium
on which a non-fixed toner image is formed passes
between the thermal fixing rollers, thus completing the
fixing process. The recording medium is then
25 discharged outside the copying machine. More
specifically, when the recording medium passes between
the thermal fixing rollers, the toner is melted by heat

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1 of the thermal fixing rollers, and when the molten
toner is pressed, it is fixed on the recording medium.

In the copying machine, in order to reliably fix
the toner as the recording agent on the recording
5 medium, the temperature control of the thermal fixing
rollers is an important factor. Therefore, in general,
a temperature sensor is arranged in the surface layer
of the fixing roller, and the heat source is
ON/OFF-controlled according to the detection value from
10 the temperature sensor. When the temperature control
is performed using the temperature sensor in the fixing
device of the copying machine, the above-mentioned
influence is a matter of concern.

In this embodiment, a change in temperature of the
15 thermal fixing rollers is calculated by the temperature
calculation algorithm of the present invention, and
temperature control is performed according to the
calculated value, thus preventing occurrence of the
above-mentioned influence.

20 (Temperature Calculation Control)

The temperature calculation control of this
embodiment is substantially the same as that in the
19th and 20th embodiments, and a change in temperature
of the fixing rollers is calculated by evaluating it
25 using a matrix calculated in advance within a range of
the thermal time constant of the fixing rollers and
input possible energy.

1 A detailed means for calculating and presuming a
change in temperature of the fixing rollers uses the
thermal conduction formulas like in the 19th and 20th
embodiments. In order to facilitate the calculation
5 processing, the formulas are developed like in the 19th
and 20th embodiments. A change in temperature
(increase in temperature) of the fixing rollers is
calculated by obtaining a decreased temperature after
an elapse of unit time from a fixing roller temperature
10 increased by energy supplied in unit time, and a total
sum of decreased temperatures at the present time from
temperatures increased in respective past unit times is
calculated as the current fixing roller temperature.

 The calculation time of a change in temperature,
15 i.e., an increase/decrease in temperature of the fixing
rollers can be greatly shortened like since a matrix
calculated in advance within a range of the thermal
time constant of the fixing rollers and possible input
energy is set as a table. In this embodiment, as shown
20 in Fig. 34, the driving duty of the fixing rollers is
set at 5% intervals, and the unit time (temperature
presumption interval) is set to be 5 sec.

 In the fixing rollers used in this embodiment,
when 60.0 sec have elapsed, the temperature increased
25 in unit time is decreased to about 0°C. For this
reason, a temperature decrease table after an elapse of
65 sec is not prepared. In the case of fixing rollers

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1 having a thermal time constant indicating a low thermal
conductivity, a table having values coping with a
decrease in increased temperature to 0°C and its
influence is preferably prepared.

5 In the method of controlling the temperature of
the thermal fixing rollers in this embodiment, an upper
limit temperature (U) and a lower limit temperature (L)
are set in advance, and when the temperature of the
thermal fixing rollers falls outside the set
10 temperature range, the ON/OFF control of the heat
source 2 is performed.

As described above, in the copying machine for
applying heat energy to the thermal fixing rollers, in
addition to the 19th embodiment,

15 (5) when the heat source for increasing the
temperature of the thermal fixing rollers is controlled
according to the temperature of the thermal fixing
rollers calculated by the temperature calculation
algorithm,

20 5. the temperature of the thermal fixing rollers
can be adequately controlled, and reliability of the
fixing characteristics can be improved.

In this embodiment, like in the 19th and 20th
embodiments, the time base of the calculation table
25 corresponds to an arithmetic progression, but need not
always correspond to the arithmetic progression. More
specifically, in order to save a memory capacity for

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1 the table, the time base of the calculation table may
be roughly set for a region where a change in
temperature is small, and increased/decreased
temperature data in unit time may be calculated and
5 presumed from adjacent data. The temperature
increase/decrease gradient of the fixing rollers may be
multiplied with a proper correction value. For
example, temperature increase/decrease data of the
calculation table may be multiplied with a correction
10 coefficient based on, e.g., passage of the recording
medium as a factor.

Various control methods for controlling the heat
source according to the temperature of the fixing
rollers can be similarly applied to a case wherein the
15 temperature calculation algorithm of the present
invention. Since individual heat source control means
is a known technique, a detailed description thereof
will be omitted.

(22nd Embodiment)

20 The 22nd embodiment wherein the present invention
is applied to a recording apparatus like in the 20th
embodiment will be described below with reference to
the accompanying drawings.

(Outline of Overall Control Flow)

25 As described above, in an ink jet recording
apparatus, when the temperature of a recording head is
controlled to fall within a predetermined region,

1 ejection and the ejection quantity can be stabilized,
and a high-quality image can be recorded. In order to
realize stable high-quality image recording, a
temperature calculation/detection means of the
5 recording head, and an optimal driving control method
according to the temperature will be briefly described
below.

(1) Setting of Target Temperature

Head driving control for stabilizing the ejection
10 quantity to be described below is made with reference
to the chip temperature of the head. More
specifically, the chip temperature of the head is used
as substitute characteristics upon detection of the
ejection quantity per dot ejected at that time.
15 However, even when the chip temperature is constant,
since the ink temperature in a tank depends on the
surrounding temperature, the ejection quantity varies.
In order to eliminate this difference, a value that
determines the chip temperature of the head for
20 obtaining equal ejection quantities in units of
surrounding temperatures (i.e., in units of ink
temperatures) is a target temperature. The target
temperature is set in advance as a target temperature
table. Fig. 35 shows the target temperature table used
25 in this embodiment.

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1 (2) Calculation means of Recording Head Temperature

The recording head temperature is presumed and calculated from energy supplied previously. In a temperature calculation method, a change in temperature
5 of the recording head is processed as the accumulation of discrete values per unit time. The changes in temperature of the recording head according to the discrete values are calculated in advance within a range of possible input energy so as to form a table.
10 In this case, the table is constituted by a two-dimensional matrix (two-dimensional table) of input energy per unit time and an elapse time.

In a temperature calculation algorithm means in this embodiment, the recording head constituted by
15 combining members having a plurality of different heat conduction times is substituted with a smaller number of thermal time constants than that in practice to form a model, and calculations are individually performed while grouping required calculation intervals and
20 required data hold times in units of models (thermal time constants). Furthermore, a plurality of heat sources are set, and temperature rise widths are calculated in units of models for each heat source. The calculated widths are added later to calculate the
25 head temperature.

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1 The reasons why the chip temperature is calculated
and presumed from input energy in place of sensing it
using a sensor are:

 ① the response time can be shortened by
5 calculating and presuming the chip temperature as
compared to the case using the sensor,
 → a change in chip temperature can be quickly
 processed; and

 ② cost can be decreased.

10 The presumed head temperature serves as a reference for
ejection driving and sub-heater driving in this
embodiment.

(3) PWM control

 When the head is driven at the chip temperature
15 described in the target temperature table in the
corresponding environment, the ejection quantity can be
stabilized. However, the chip temperature varies from
time to time according to, e.g., the print duty, and is
not constant. For this reason, a means for driving the
20 head in a multi-pulse PWM driving mode and controlling
the ejection quantity independently of the temperature
for the purpose of stabilizing the ejection quantity is
PWM control. In this embodiment, a PWM table, which
defines a pulse having an optimal waveform and width at
25 that time according to a difference between the head
temperature and the target temperature in the

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1 corresponding environment, is set in advance, thereby
determining an ejection driving condition.

(4) Sub-heater Driving Control

Control for driving sub-heaters immediately before
5 printing to approach the head temperature to the target
temperature when a desired ejection quantity cannot be
obtained even by PWM driving is sub-heater control. An
optimal sub-heater driving time at that time is set in
advance according to a difference between the head
10 temperature and the target temperature in the
corresponding environment, thereby determining a
sub-heater driving condition.

Principal control operations of this embodiment
will be individually described below.

15 (Temperature Prediction Control)

Briefly speaking, a change in head temperature is
calculated by estimating it using a matrix calculated
in advance within a range of the thermal time constant
of the head and possible input energy. The detailed
20 means for calculating and presuming a change in
temperature of the recording head uses the
above-mentioned heat conduction formula (1) in heating,
and uses the above-mentioned heat conduction formula
(2) in cooling started during heating like in the 20th
25 embodiment.

When the recording head is processed as a lumped
constant system, the chip temperature of the recording

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1 head can be theoretically presumed by calculating the
formulas (1) and (2) according to the print duty in
correspondence with a plurality of thermal time
constants.

5 However, in general, it is difficult to perform
the above-mentioned calculations without modifications
in terms of a problem of the processing speed.

• Strictly speaking, all the constituting members
have different time constants, and another time
10 constant is formed between adjacent members, resulting
in a huge number of times of calculations.

• In general, since an MPU cannot directly perform
exponential calculations, approximate calculations must
be performed, or calculations using a conversion table
15 must be performed, thus disturbing a decrease in
calculation time.

This embodiment solves the above-mentioned
problems by the following modeling and calculation
algorithm.

20 (1) Modeling

The present inventors sampled data in the
temperature rise process of the recording head by
applying energy to the recording head with the above
arrangement, and obtained the result shown in Fig. 36.
25 Strictly speaking, the recording head with the above
arrangement is constituted by combining many members
having different heat conduction times. However,

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1 Fig. 36 reveals that such many heat conduction times
can be processed as a heat conduction time of a single
member in practice in ranges where the differential
value of the function of the log-converted increased
5 temperature data and the elapse time is constant (i.e.,
ranges A, B, and C having constant inclinations).

From the above-mentioned result, in a model
associated with heat conduction, this embodiment
processes the recording head using two thermal time
10 constants. Note that the above-mentioned result
indicates that feedback control can be more precisely
performed upon modeling having three thermal time
constants. However, in this embodiment, it is
determined that the inclinations in areas B and C in
15 Fig. 36 are almost equal to each other, and the
recording head is modeled using two thermal time
constants in consideration of calculation efficiency.
More specifically, one heat condition is a model having
a time constant at which the temperature is increased
20 to the equilibrium temperature in 0.8 sec
(corresponding to the area A in Fig. 36), and the other
heat conduction is given by a model having a time
constant at which the temperature is increased to the
equilibrium temperature in 512 sec (i.e., a model of
25 the areas B and C in Fig. 36).

1 Furthermore, this embodiment processes the
recording head as follows to obtain a model.

• The temperature distribution in heat conduction
is assumed to be ignored, and the entire recording head
5 is processed as a lumped constant system.

• The heat source assumed to include two heat
sources, i.e., a heat source for the print operation,
and a heat source as sub-heaters.

Fig. 37 shows a heat conduction equivalent circuit
10 modeled in this embodiment. Fig. 37 illustrates only
one heat source. However, when two heat sources are
used, they may be connected in series with each other.

(2) Calculation Algorithm

In the head temperature calculations of this
15 embodiment, the above-mentioned formulas are developed
to formulas <2-1>, <2-2>, <2-3>, ..., <2-n> like in the
20th embodiment so as to facilitate the calculation
processing. More specifically, a change in head
temperature (increase in temperature) is obtained by
20 calculating a decreased temperature after an elapse of
unit time from the head temperature increased by energy
supplied in unit time (corresponding to each of the
formulas <2-1>, <2-2>, ..., <2-n>), and a total sum of
decreased temperatures at the present time from
25 temperatures increased in respective past unit times is
calculated to presume the current head temperature
($\langle 2-1 \rangle + \langle 2-2 \rangle + \dots + \langle 2-n \rangle$).

1 In this embodiment, the chip temperature of the
recording head is calculated (heat source 2 *
thermal time constant 2) four times based on the
above-mentioned modeling. The required calculation
5 times and data hold times for the four calculations are
as shown in Fig. 38. Figs. 39 to 42 show calculation
tables used for calculating the head temperature, and
each comprising a two-dimensional matrix of input
energy and elapse time. Fig. 39 shows a calculation
10 table when ejection heaters are used as heat source,
and a member group having a short-range time constant
is used; Fig. 40 shows a calculation table when
ejection heaters are used as the heat source, and a
member group having a long-range time constant is used;
15 Fig. 41 shows a calculation table when sub-heaters are
used as the heat source, and a member group having a
short-range time constant is used; and Fig. 42 shows a
calculation table when sub-heaters are used as the heat
source, and a member group having a long-range time
20 constant is used.

As shown in Figs. 39 to 42, calculations are
performed at 0.05-sec intervals to obtain:

- 25 (1) an increase (in degrees) in temperature of a
member having a time constant represented by the short
range upon driving of the ejection heaters (ΔT_{mh});
- (2) an increase (in degrees) in temperature of a
member having a time constant represented by the short
range upon driving of the sub-heaters (ΔT_{sh}); =

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1 calculations are performed at 1.0-sec intervals to
obtain:

(3) an increase (in degrees) in temperature of a
member having a time constant represented by the long
5 range upon driving of the ejection heaters (ΔT_{mb}); and

(4) an increase (in degrees) in temperature of a
member having a time constant represented by the long
range upon driving of the sub-heaters (ΔT_{sb}).

The above-mentioned calculations are sequentially
10 performed, and ΔT_{mh} , ΔT_{sh} , ΔT_{mb} , and ΔT_{sb} are added to
each other ($= \Delta T_{mh} + \Delta T_{sh} + \Delta T_{mb} + \Delta T_{sb}$), thus
calculating the head temperature at that time.

As described above, since the recording head
constituted by combining a plurality of members having
15 different heat conduction times is modeled to be
substituted with a smaller number of thermal time
constants than that in practice, the following effects
can be obtained.

- As compared to a case wherein calculation
20 processing is faithfully performed in units of all the
members having different heat conduction times, and in
units of thermal time constants between adjacent
members, the calculation processing volume can be
greatly decreased without impairing calculation
25 precision so much.

- Since the head is modeled with reference to time
constants, calculation processing can be performed in a

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1 small number of processing operations without impairing
calculation precision. For example, in the
above-mentioned case, when the head is not modeled in
units of time constants, the calculation interval
5 requires 50 msec since it is determined by the area A
having a small time constant. On the other hand, the
data hold time of discrete data requires 512 sec since
it is determined by the areas B and C having a large
time constant. More specifically, accumulation
10 calculation processing of 10,240 data for last 512 sec
must be performed at 50-msec intervals, resulting in
the number of calculation processing operations several
hundreds of times that of this embodiment.

As described above, in addition to the temperature
15 calculation algorithm in the 20th embodiment, in this
embodiment, the recording head constituted by combining
a plurality of members having different heat conduction
times is modeled to be substituted with a smaller
number of thermal time constants than that in practice,
20 and calculations are individually performed while
grouping required calculation intervals and required
data hold times in units of model units (thermal time
constants). Furthermore, a plurality of heat sources
are set, temperature rise widths are calculated in
25 units of model units for each heat source, and the
calculated widths are added later to calculate the head
temperature (plural heat source calculation algorithm).

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1 Thus, a change in temperature of the recording head can
be processed by calculations even in a low-cost
recording apparatus without arranging a temperature
sensor in the recording head.

5 Moreover, the above-mentioned PWM driving control
and sub-heater control for controlling the temperature
of the recording head within a predetermined range can
be properly performed, and ejection and the ejection
quantity can be stabilized, thus allowing recording of
10 a high-quality image.

Figs. 43A and 43B compare the recording head
temperature presumed by the head temperature
calculation method described in this embodiment, and
the actually measured recording head temperature using
15 the recording head with the above-mentioned
arrangement. In Figs. 43A and 43B,

abscissa: elapse time (sec)

ordinate: increased temperature (Δt)

print pattern; (25% duty * 5 lines + 50% duty * 5
20 lines + 100% duty * 5 lines) * 5
times (a total of 75 lines printed)

Fig. 43A; change in recording head temperature
presumed by the head temperature
calculation means

25 Fig. 43B; actually measured change in recording
head temperature

1 As can be seen from Figs. 43A and 43B, the head
temperature can be precisely presumed by the
temperature calculation method of this embodiment.
(PWM Control)

5 In this embodiment, double-pulse PWM control is
performed like in the 20th embodiment. However, other
multi-pulse PWM control methods such as triple-pulse
PWM control may be employed, or a main pulse PWM
driving method for modulating a main pulse width by a
10 single pulse may be employed.

 In this embodiment, control is made to uniquely
set a PWM value based on a temperature difference (ΔT)
between the target temperature (Fig. 35) and the head
temperature. Fig. 44 shows the relationship between ΔT
15 and the PWM value. In Fig. 44, "temperature
difference" represents ΔT , "pre-heat" represents P_1 ,
"interval" represents P_2 , and "main" represents P_3 .
Also, "set-up time" indicates a time from when a
recording command is input until the pulse P_1 is
20 actually raised. This time is mainly determined by a
margin time until the driver is enabled, and is not a
principal value in the present invention. In addition,
"weight" represents the weighting coefficient to be
multiplied with the number of print dots, which is
25 detected for calculating the head temperature. Even
when the number of print dots remains the same, an
increase in head temperature varies depending on a

1 pulse width, e.g., between a case wherein the print
operation is performed to have a pulse width of 7 μ s
and a case wherein the print operation is performed to
have a pulse width of 4.5 μ s. As a means for
5 correcting a difference in the increase in temperature
due to PWM control depending on the selected PWM table,
the "weight" is used.

(Sub-heater Driving Control)

When an actual ejection quantity is below a
10 reference ejection quantity even after the PWM driving
means is executed, the sub-heater driving control is
performed immediately before the print operation, so
that the ejection quantity becomes equal to the
reference ejection quantity. The sub-heater driving
15 time is set from a sub-heater table according to a
difference (Δt) between the target temperature and the
actual head temperature. Two sub-heater tables, i.e.,
"rapid acceleration sub-heater table" and "normal
sub-heater table", are prepared, and are selectively
20 used according to the following conditions (see
Fig. 45).

[When print operation is restarted from non-print
state]

When 10 sec or more have elapsed from the end of
25 the previous print operation, the "rapid acceleration
sub-heater table" is used. Before an elapse of 10 sec,
the "normal sub-heater table" is used.

1 [When continuous print operation is performed]

When 5 sec or more have elapsed after the print operation is restarted from the non-print state, the "normal sub-heater table" is used. Before an elapse of
5 5 sec, the table used at the beginning of the print operation is used. More specifically, when the rapid acceleration sub-heater table is used, the "rapid acceleration sub-heater table" is used; when the normal sub-heater table is used, the "normal sub-heater table"
10 is used.

The reason why the two tables are selectively used, and the rapid acceleration sub-heater table is used is as follows. That is, since the ejection control means using the sub-heaters is a means for
15 controlling the ejection quantity by increasing the head temperature, a temperature rise operation requires much time. When the required temperature rise operation is not completed within the lamp-up time of the carriage, the start of the print operation must be
20 delayed until the temperature rise operation is completed, thus decreasing the throughput.

Fig. 46 shows details of the sub-heater driving conditions. In Fig. 46, "temperature difference" represents the difference (Δt) between the target
25 temperature and the actual head temperature, "LONG" represents the rapid acceleration sub-heater table, and "SHORT" represents the normal sub-heater table.

1 (Overall Flow Control)

The flow of the overall control system will be described below with reference to Figs. 47 and 48.

Fig. 47 shows an interrupt routine for setting a
5 PWM driving value for ejection, and a sub-heater driving time. This interrupt routine is called at 50-msec intervals. Therefore, the PWM value and the sub-heater driving time are updated at every 50 msec regardless of a print or non-print state, or an
10 environment requiring or not requiring the driving operation of the sub-heaters.

When the interrupt routine is called at a 50-msec interval, the print duty for last 50 msec is referred to (S2010). The print duty to be referred to at this
15 time is a value obtained by multiplying the number of actually ejected dots with a weighting coefficient in units of PWM values, as has been described above in the paragraph of (PWM Control). The increased temperature (ΔT_{mh}) of a member group when the ejection heaters are
20 used as a heat source and the short-range time constant is used is calculated based on the print duty for last 50 msec, and the print history for last 0.8 sec (S2020). Similarly, the driving duty of the sub-heaters for last 50 msec is referred to (S2030),
25 and the increased temperature (ΔT_{sh}) of a member group when the sub-heaters are used as a heat source and the short-range time constant is used is calculated based

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1 on the driving duty of the sub-heaters for last 50
msec, and the print history for last 0.8 sec (S2040).
Then, the increased temperature (ΔT_{mb}) of a member
group when the ejection heaters are used as a heat
5 source and the long-range time constant is used, and
the increased temperature (ΔT_{sb}) of a member group when
the sub-heaters are used as a heat source and the
long-range time constant is used, which temperatures
have been calculated in the main routine (to be
10 described later), are referred to, and the
above-mentioned temperatures are added to each other ($=$
 $\Delta T_{mh} + \Delta T_{sh} + \Delta T_{mb} + \Delta T_{sb}$), thus calculating the head
temperature (S2050).

The target temperature is set from the target
15 temperature table (S2060), and the temperature
difference (ΔT) between the head temperature and the
target temperature is calculated (S2070). A PWM value
as the optimal head driving condition according to ΔT
is set based on the temperature difference ΔT and the
20 PWM table (S2080). The sub-heater driving time (S2100)
as the optimal head driving condition according to the
temperature difference ΔT is set on the basis of the
selected sub-heater table (S2090). Thus, the interrupt
routine is ended.

25 Fig. 48 shows the main routine. When a print
command is input in step S3010, the print duty for last
1 sec is referred to (S3020). In this case, the print

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1 duty to be referred to at this time is a value obtained
by multiplying the number of actually ejected dots with
a weighting coefficient in units of PWM values, as has
been described above in the paragraph of (PWM Control).
5 The increased temperature (ΔT_{mb}) of a member group when
the ejection heaters are used as a heat source and the
long-range time constant is used is calculated based on
the duty for the last 1 sec, and the print history for
last 512 sec, and is stored and updated at a memory
10 position, which is determined to be easily referred to
in the interrupt routine called at 50-msec intervals
(S3030). Similarly, the driving duty of the
sub-heaters for last 1 sec is referred to (S3040), and
the increased temperature (ΔT_{sb}) of a member group when
15 the sub-heaters are used as a heat source and the
long-range time constant is used is calculated based on
the driving duty of the sub-heaters for last 1 sec, and
the driving history of the sub-heaters for last 512
sec. The temperature ΔT_{sb} is stored and updated at a
20 memory position, which is determined to be easily
referred to in the interrupt routine called at each
50-msec interval, in the same manner as in a case
wherein ΔT_{mb} is stored and updated (S3050).

The sub-heaters are driven according to the PWM
25 value and the sub-heater driving time, which are
updated in the interrupt routine called at each 50-msec

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1 interval (S3060), and thereafter, the print operation
for one line is performed (S3070).

In this embodiment, the double- and single-pulse
PWM control methods for controlling the ejection
5 quantity and the head temperature are used.

Alternatively, PWM control using three or more pulses
may be used. When the head chip temperature is higher
than the print target temperature, and cannot be
decreased by PWM control with small energy, the
10 carriage scan speed may be decreased, or the carriage
scan start timing may be controlled.

In this embodiment, since a future head
temperature can be predicted without using a
temperature sensor, various head control operations can
15 be performed before an actual print operation, and
recording can be more properly performed. Since the
model of the recording head is simplified, and the
calculation algorithm is realized by accumulating
simple calculations, prediction control can also be
20 facilitated. Constants such as temperature prediction
cycles (50-msec intervals and 1-sec intervals) used in
this embodiment are merely examples, and the present
invention is not limited to these.

(23rd Embodiment)

25 A method for presuming the current temperature
from a print ratio (to be referred to as a print duty
hereinafter), and controlling a recovery sequence for

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1 stabilizing ejection in an ink jet recording apparatus
will be described below. When the above-mentioned PWM
control is not performed, the print duty is equal to
the power ratio.

5 In this embodiment, the current head temperature
is presumed from the print duty like in the 19th
embodiment described above, and a suction condition is
changed according to the presumed head temperature like
in Fig. 21 (ninth embodiment) presented previously.

10 (24th Embodiment)

The current head temperature is presumed from the
print duty like in the 23rd embodiment. However, in
this embodiment, a pre-ejection condition is changed
according to the presumed head temperature. This
15 embodiment corresponds to the 10th embodiment.

When the head temperature is high, the ejection
quantity is undesirably increased, and pre-ejection may
be performed in an unnecessary quantity. In this case,
control can be made to decrease the pre-ejection pulse
20 width. Fig. 49 shows the relationship between the
presumed head temperature and the pulse width. Since
the ejection quantity is increased as the temperature
becomes higher, the pulse width is decreased to
suppress the ejection quantity.

25 Since variations in temperature among nozzles are
increased as the temperature becomes higher, the
distribution of the number of pre-ejection pulses must

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1 be optimized. Fig. 50 shows the relationship between
the presumed head temperature and the number of
pre-ejection pulses. Even at room temperature, the
nozzle end portions and the central portions have
5 different numbers of pre-ejection pulses, thus
suppressing the influence caused by variations in
temperature. Since the temperature difference between
the end portion and the central portion is increased as
the head temperature becomes higher, the difference
10 between the number of pre-ejection pulses is also
increased. In this manner, variations in temperature
distribution among the nozzles can be suppressed, and
efficient (required minimum) pre-ejections can be
performed, thus allowing stable ejection.

15 Furthermore, when a plurality of heads are used,
pre-ejection temperature tables may be changed in units
of ink colors. Fig. 51 shows a temperature table.
When the head temperature is high, since the viscosity
of Bk (black) containing a larger amount of dye than Y
20 (yellow), M (magenta), and C (cyan) tends to be
increased, the number of pre-ejection pulses must be
relatively increased. Since the ejection quantity is
increased as the temperature becomes higher, the number
of pre-ejection pulses is decreased.

25 (25th Embodiment)

In this embodiment, various recovery processing
operations are performed according to the head

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1 temperature presumed like in the 19th embodiment, thus
stabilizing ejection. The various recovery processing
operations are the same as those in the 11th to 14th
embodiments described previously, and a detailed
5 description thereof will be omitted.

As described above, according to the present
invention, since a change in temperature of an object
with respect to input energy can be calculated and
presumed without providing a temperature sensor to the
10 object, the temperature of the object can be quickly
and precisely obtained independently of the error,
precision, and response performance of the temperature
sensor.

Since a recording apparatus of the present
15 invention comprises, as described above, a modeling
means for modeling a recording head constituted by
combining a plurality of members having different heat
conduction times to be substituted with a smaller
number of thermal time constants than that in practice,
20 a calculation algorithm means for individually
performing calculations while grouping required
calculation intervals and required data hold times in
units of models (thermal time constants), and a plural
heat source calculation algorithm means for setting a
25 plurality of heat sources, calculating temperature rise
widths in units of models for each heat source, and
then adding the calculated widths to calculate the head

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1 temperature, a change in temperature of the recording
head can be processed by calculation processing even in
a low-cost recording apparatus without providing a
temperature sensor to the recording head. Furthermore,
5 a recording apparatus, which can stabilize recording,
e.g., the ejection quantity and ejection according to
the precise and quick-response change in temperature of
the recording head obtained by the above-mentioned
calculations, can be provided.

10 (26th Embodiment)

The arrangement of this embodiment is the same as
that shown in Figs. 1 to 3 and Fig. 16. This
embodiment will be described in detail below with
reference to the accompanying drawings.

15 (Summary of Temperature Prediction)

In this embodiment, upon execution of recording by
ejecting ink droplets from a recording head, a
surrounding temperature sensor for measuring the
surrounding temperature is provided to a main body
20 side, and a change in temperature of an ink in an
ejection unit from the past to the present is presumed
by calculation processing of ejection energy of the
ink, thereby stabilizing ejection according to the ink
temperature. More specifically, in this embodiment, no
25 temperature detection member for directly detecting the
temperature of the recording head is used.

1 (27th Embodiment)

A PWM ejection quantity control method in which the number of ON pulses per ejection is 3 (three divided pulses; triple-pulse PWM) will be described
5 below. The driving operation of the recording head is controlled by a multi-pulse PWM driving method using ejection heaters on the basis of the presumed ink temperature. In this embodiment, control is made to obtain a constant ejection quantity by PWM ejection
10 quantity control (to be described below) based on the ink temperature.

(PWM Control)

The PWM ejection quantity control method of this embodiment will be described in detail below with
15 reference to the accompanying drawings. Fig. 52 is a timing chart of common signals and segment signals in a head using a known diode matrix. The command signals are output eight times in turn in a minimum driving period of the recording head regardless of the content
20 of print data, and during the ON period of each common signal, the segment signals whose ON/OFF intervals are determined according to a print signal are turned on. A current flows through the ejection heaters when the command and segment signals are simultaneously turned
25 on. In this embodiment, ejection ON/OFF control of each of 64 nozzles can be performed. In this embodiment, the segment signals are controlled by

1 multi-pulse PWM control based on interval time control,
thus realizing ejection quantity control as well as
ON/OFF control.

Figs. 53A and 53B are views for explaining divided
5 pulses according to the embodiment of the present
invention. In Fig. 53A, V_{OP} represents the operational
voltage, T1 represents the pulse width of the first one
of a plurality of divided heat pulses, which pulse does
not cause bubble production (to be referred to as a
10 pre-pulse hereinafter), T2 represents the interval
time, and T3 is the pulse width of the second pulse,
which causes bubble production (to be referred to as a
main pulse hereinafter). The operational voltage V_{OP}
represents electrical energy necessary for causing an
15 electrothermal converting element applied with this
voltage to generate heat energy in the ink in an ink
channel constituted by a heater board and a top plate.
The value of this voltage is determined by the area,
resistance, and film structure of the electrothermal
20 converting element, and the channel structure of the
recording head.

The PWM ejection quantity control of this
embodiment can also be referred to as an interval time
with a modulation driving method. For example, in the
25 case of triple-pulse PWM control, the pulses are
applied in turn to have the widths T1, T2, and T3 upon
ejection of one ink droplet. At this time, the width

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1 of the interval time T2 is modulated according to the
ink temperature and an ejection quantity modulation
signal. The pre-pulse is a pulse for applying heat
energy to the ink temperature in the ink channel so as
5 not to cause bubble production. The interval time
controls a time required for conducting the pre-pulse
energy to the ink in the ink channel, and plays an
important role in this embodiment. The main pulse
causes bubble production in the ink in the ink channel,
10 and ejects the ink from an ejection orifice. The width
T3 of the main pulse is preferably determined by the
area, resistance, and film structure of the
electrothermal converting element, and the channel
structure of the recording head.

15 In the PWM control described previously with
reference to Fig. 10, when the ejection quantity is to
be increased, the pulse width of the pulse T1 must be
increased to increase heat energy itself to be supplied
to the recording head. For this reason, when a pulse
20 value having large T1 is continuously input, the
temperature of the head itself is undesirably
increased. As a result, since the temperature of the
head itself is increased, when the ejection quantity is
to be decreased in turn, the ejection quantity cannot
25 often be decreased to a desired quantity.

Also, in the power supply design at the main body
side, when the maximum ejection quantity is to be

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1 obtained in the above-mentioned control, extra
electrical power of about 40% must be input, and the
power supply, flexible circuit board, and the like must
be designed using this maximum value from the
5 beginning. An increase in cost for this design is very
large. In a portable printer, a battery driving
operation is indispensable, and an increase in
electrical power decreases the number of printable
pages. In particular, at low temperature, since the
10 pulse width is shifted to be larger, the number of
printable pages is further decreased in an environment
where battery performance is impaired.

In this embodiment, the width T1 of the pre-pulse
is left unchanged, and the interval time T2 between the
15 pre-pulse T1 and the main pulse T3 is set to be
variable, thus allowing ejection quantity control by
controlling the heat conduction time. According to
this control, most of the above-mentioned drawbacks can
be solved. A PWM control means of this embodiment will
20 be described below.

In the recording head shown in Figs. 8A and 8B,
when the operational voltage $V_{OP} = 18.0$ (V), the main
pulse width $T3 = 4.000$ [μsec], and the pre-pulse width
 $T1 = 1.000$ [μsec] are set, and the interval time T2 is
25 changed between 0 and 10 [μsec], the relationship
between an ejection quantity V_d [pl/drop] and the

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1 interval time T_2 [μsec], as shown in Fig. 54, is
obtained.

Fig. 54 is a graph showing the pre-pulse width
dependency of the ejection quantity in this embodiment.
5 In Fig. 54, V_0 indicates the ejection quantity when $T_2 =$
0 [μsec], and this value is determined by the head
structure shown in Figs. 8A and 8B. In this
embodiment, $V_0 = 70.0$ [pl/drop] when a surrounding
temperature $T_R = 23^\circ\text{C}$. As indicated by the curve shown
10 in Fig. 54, the ejection quantity V_d is nonlinearly
increased to a given region up to the saturation point
according to an increase in interval time T_2 , and shows
saturated characteristics for a while. Thereafter, the
ejection quantity V_d presents a slow descent curve.

15 In this manner, a range until the change in
ejection quantity V_d with respect to the change in
interval time T_2 is saturated is effective as a range
wherein the ejection quantity can be easily controlled
by changing the interval time T_2 . In this embodiment
20 indicated by the curve in Fig. 54, T_2 can be used up to
 $T_2 \approx 8.00$ (μs) in practice. The maximum ejection
quantity at this time was 85.0 [pl/drop] in a 15°C
environment, and was 91 [pl/drop] in a 23°C
environment.

25 However, when the pulse width is still large, the
ejection quantity V_d is gradually decreased from the
maximum value. This phenomenon occurs for the

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1 following reason. In the principle of the ejection
quantity control, when the pre-pulse is applied, and
the ink at the interface between the electrothermal
converting element and the ink is heated within a
5 bubble non-production range, only a portion very close
to the surface of the electrothermal converting element
is heated since the heat conduction speed of the ink is
low, and the degree of activation of this portion is
increased. Thus, the evaporation quantity of this
10 portion in response to the next main pulse is changed
according to the increased degree of activation, and as
a result, the ejection quantity can be controlled. For
this reason, when the heat conduction time is too long
(when the pulse width is too large), heat is
15 excessively diffused in the ink, and the degree of
activation of the ink is decreased in an actual bubble
production range in response to the next main pulse.

An increase in ejection quantity due to an
increase in interval time T_2 will be described in
20 detail below. As shown in Fig. 55, since a
multi-layered coating such as a protection film is
formed on the heater surface, the center of the heater
exhibits the highest temperature, the temperature is
slightly decreased toward the interface with the ink, a
25 temperature distribution representing an abrupt change
is formed at the interface with the ink, and
thereafter, a moderate distribution is shown. Fig. 56

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1 shows a one-dimensional temperature distribution of a
section perpendicular to the heater surface in a
conventional single-pulse driving method and the
multi-pulse driving method. The temperature
5 distribution shown in Fig. 56 is one after an elapse of
the interval time T2 after the pre-pulse T1 is input,
and immediately before film boiling in the main pulse
T3 occurs. A curve of the single-pulse driving method
also represents a temperature distribution after the
10 single pulse is applied and immediately before film
boiling occurs.

At this time, the temperature distribution in the
ink is as shown in Fig. 56. As can be seen from
Fig. 56, the thickness of an ink layer having a high
15 temperature although its peak temperature is low is
larger in the multi-pulse method than that in the
single-pulse method. When film boiling occurs at the
next moment in this state, a portion above a
temperature indicated by an oblique dotted line is
20 actually evaporated, and serves as a portion associated
with bubble production. More specifically, the ink
portion having a thickness indicated by a vertical
dotted line in the graph of the temperature inside the
ink is evaporated, and the bubble production volume in
25 the multi-pulse method is larger than that in the
single-pulse method. As a result, the ejection
quantity is increased.

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1 The multi-pulse PWM control based on the interval
time control method is characterized in that input
energy is set to have a minimum constant value, and the
thickness of the ink layer (bubble production volume)
5 to be evaporated is controlled according to a heat
conduction time from the input of the pre-pulse T1
until the beginning of film boiling. More
specifically, when the interval time is increased,
although the peak temperature of the ink is decreased,
10 the region of the (activated) ink layer, which is
actually evaporated in response to the next main pulse,
and is associated with bubble generation, is increased.

 This embodiment is suitable for high-speed driving
since a control region varies from the interval time =
15 0 to a value (8 μ sec in Fig. 54) corresponding to the
saturated ejection quantity. More specifically, a
region after the value (8 μ sec in Fig. 54)
corresponding to the saturated ejection quantity may be
used as a control region. However, since a time
20 required for one ejection is increased, the latter
region is not suitable for high-speed driving. For
example, when the pre-pulse width T1 = 1.000 [μ sec] and
the main pulse width T3 = 4.000 [μ sec] are set, and the
interval time T2 is changed between 0 and 8 [μ sec], a
25 time required for one ejection is a maximum of 13
[μ sec]. However, when the interval time T2 is changed
from 8 to 20 [μ sec], 25 [μ sec] are required.

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1 As described above, according to this embodiment,
the ejection quantity control is performed by
controlling the ejection quantity by changing the
interval time T2, i.e., by controlling the thickness of
5 the ink layer at active level according to a heat
conduction time after a minimum necessary heat amount
is applied, in place of changing the pre-pulse width
T1, i.e., in place of forcibly and abruptly applying
heat energy to the ink having low heat conductivity
10 with a large temperature gradient up to active level
immediately before film boiling occurs.

 With the above-mentioned new principle, the
following effects are obtained. The first effect is a
widened controllable range, as described above. When
15 the pre-pulse width T1 is increased to increase the
ejection quantity, the ink temperature approaches a
pre-bubble region. However, since this embodiment is
free from such a problem, the control range can be
widened independently of variations of recording heads.

20 The second effect is an energy saving effect. In
this embodiment, since an increase in bubble production
efficiency is realized by increasing heat efficiency
based on the heat conduction time, energy supplied to
the recording head need not be increased, i.e., a
25 minimum energy level can be set. In other words, in
this embodiment, as the ejection quantity is increased,
the heat efficiency can be improved, and the required

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1 heat amount per unit ejection volume is decreased.
Therefore, in the design of the main body power supply,
flexible cable, connector, and battery, as described
above, only a minimum capacity is required. In the
5 method of controlling the pre-pulse width, since the
pulse width must be increased to continuously increase
the ejection quantity, input energy is undesirably
increased by a maximum of about 40%, and an increase in
temperature of the recording head itself is promoted.
10 However, the temperature of the recording head is not
increased, and the increase in temperature of the head
itself is suppressed by the improved heat efficiency.

In an actual ejection quantity control method, a
temperature range described as "PWM control region" in
15 Fig. 57 is a temperature range in which the ejection
quantity can be stabilized. In this embodiment, this
temperature range corresponds to a range between 15°C
and 35°C of the ink temperature in the ejection unit.
Fig. 57 shows the relationship between the ink
20 temperature in the ejection unit and the ejection
quantity when the interval time is changed in 10 steps.
Even when the ink temperature in the ejection unit
changes, the ejection quantity can be controlled within
a width ΔV with respect to a target ejection quantity
25 V_{d0} by changing the interval time at every temperature
step width ΔT according to the ink temperature.

1 (Temperature Prediction Control)

Operations upon execution of recording using the recording apparatus with the above arrangement will be described below with reference to the flow charts shown
5 in Figs. 58 and 59.

Since operations from when the power switch is turned on in step S700 until a print signal is input in step S760 are the same as those in steps S100 to S160 in Fig. 17, a detailed description thereof will be
10 omitted.

When the print signal is input, a target (driving) temperature table (Fig. 60) is referred to, thus obtaining a print target temperature (α) of the head chip at which optimal driving is attached at the
15 current surrounding temperature (S770). In Fig. 60, the same table as Table 6 presented previously may be used although the target temperatures are different. In step S780, γ ($= \alpha - \beta$) is calculated.

Then, the interval time T2 is determined with
20 reference to Fig. 61A for the purpose of controlling the ejection quantity using the PWM method (S790).

During a one-line print operation, the chip temperature of the head changes according to its ejection duty. More specifically, since the difference
25 (γ) sometimes changes even in one line, the interval time is preferably optimized in one line according to the change in γ . In this embodiment, the one-line

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1 print operation requires 1.0 sec. Since the
temperature prediction cycle of the head chip is 0.1
sec, one line is divided into 10 areas in this
embodiment. The interval time at the beginning of
5 printing, which value is set previously, is an interval
time at the beginning of printing of the first area.

A method of determining the interval time at the
beginning of printing of each of the second to 10th
areas will be described below. In step S800, $n = 1$ is
10 set, and in step S810, n is incremented. In this case,
 n represents the area, and since there are 10 areas,
the control escapes from the following loop when n
exceeds 10 (S820).

In the first round of the loop, the interval time
15 at the beginning of printing of the second area is set.
More specifically, the power ratio of the first area is
calculated based on the number of dots and the PWM
value of the first area (S830). The power ratio
corresponds to a value plotted along the ordinate when
20 the temperature prediction table is referred to. In
this case, the head chip temperature (β) at the end of
printing of the first area (i.e., at the beginning of
printing of the second area) is predicted by
substituting the power ratio in the temperature
25 prediction table (Fig. 20) (i.e., by referring to the
table) (S840). In step S850, the difference (γ)
between the print target temperature (α) and the head

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1 chip temperature (β) is calculated again. The interval
time T2 for printing the second area is obtained based
on the difference (γ) by referring to Fig. 61, and the
interval time of the second area is set on the memory
5 (S860).

Thereafter, the power ratio in the corresponding
area is calculated based on the number of dots and the
interval time of the immediately preceding area,
thereby predicting the head chip temperature (β) at the
10 end of printing of the corresponding area. Then, the
interval time of the next area is set based on the
difference (γ) between the print target temperature (α)
and the head chip temperature (β) (S820 to S860).
Thereafter, when the interval times for all the 10
15 areas in one line are set, the flow advances from step
S820 to step S870, and the sub-heaters are heated
before printing. Thereafter, the one-line print
operation is performed according to the set interval
times. Upon completion of the one-line print operation
20 in step S870, the flow returns to step S720 to read the
temperature of a reference thermistor, and the
above-mentioned control operations are sequentially
repeated.

With the above-mentioned control, since the actual
25 ejection quantity can be stably controlled regardless
of the ink temperature, a high-quality recorded image
having a uniform density can be obtained.

1 (28th Embodiment)

The 28th embodiment of the present invention, capable of widening a control region of an ejection quantity will be described below.

5 In the 27th embodiment, the interval time in the double-pulse PWM driving method is controlled to control the ejection quantity in all the environments. However, in the 28th embodiment, sub-heaters are also used according to the surrounding temperature, so that
10 the temperature range of the recording head, in which the ejection quantity can be controlled, is widened.

The temperature range of the recording head, in which the ejection quantity can be controlled, in the 28th embodiment will be described below. The
15 characteristics of the recording head used in the 27th and 28th embodiments and the ejection quantity per dot suitable for image formation are as follows:

Ejection quantity change width controlled by
changing interval time; +30%

20 Temperature dependency coefficient (KT); 0.8
[pl/°C]

Optimal ejection quantity: 85 pl

Assuming that the surrounding temperature range, in which the apparatus can be used, and the print
25 density is assured, is a range between 15°C and 35°C, the recording head must be arranged to obtain an ejection quantity of 85 pl when the surrounding

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1 temperature is 15°C (recording head temperature =
15°C), and the PWM value for maximizing the ejection
quantity (to be referred to as PWMmax hereinafter) is
set. At this time, an ejection quantity of 65 pl is
5 obtained when the PWM value for minimizing the ejection
quantity is set (to be referred to as PWMmin
hereinafter). When this head is used at a surrounding
temperature of 35°C, since the temperature dependency
coefficient is 0.8, the ejection quantity is increased
10 by 16 pl, and 81 pl are obtained by PWMmin. When a
difference from the optimal ejection quantity is up to
4 pl, i.e., when an increase in temperature of the
recording head itself by the print operation is up to
5°C, the actual ejection quantity can be controlled to
15 be equal to the optimal ejection quantity. However,
when the increase in temperature of the recording head
itself exceeds 5°C, it is impossible to control the
actual ejection quantity. Factors that limit the
useable temperature width of the recording head are two
20 factors, i.e., the ejection quantity control width of
PWM driving and the temperature dependency coefficient.
If the ejection quantity change width is 20 pl, and the
temperature dependency coefficient is 0.8, the useable
temperature range of the recording head is inevitably
25 limited to 25°C.

Thus, in this embodiment, when the surrounding
temperature is low, control for heating the recording

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1 head using the sub-heaters is performed in addition to
the control in the 27th embodiment. Thus, a low
recording head temperature need not be assumed, and the
useable temperature range can be shifted toward the
5 upper limit side. For this reason, the condition of a
useable temperature can be expanded in a practical use.
In this embodiment, although control is made also using
the sub-heaters, since the ejection quantity is
controlled by the method of the 27th embodiment without
10 increasing the pre-pulse width, input energy conversion
efficiency can be improved. For this reason, an
increase in temperature can be suppressed, and an
ejection quantity control range can be further widened
even when print quality equivalent to that in the prior
15 art is to be obtained.

This embodiment will be described in detail below
with reference to the accompanying drawings. In this
embodiment, an allowable variation range of the actual
ejection quantity is a range between 85 and 90 pl, and
20 four ranks of PWM values are set. That is, PWM values
PWM1, PWM2, PWM3, and PWM4 are set from a smaller
ejection quantity side. The PWM value PWM4 is 1.3
times the ejection quantity ratio of PWM1, and other
PWM values are set to have the same ratio. Fig. 63
25 shows details (pre-pulse widths, interval times, main
pulse widths, and the like) of the PWM values. In this

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1 embodiment, the PWM values are changed immediately
before the print operation of each line.

Fig. 62 shows the relationship between the
recording head temperature, the selected PWM value, and
5 the ejection quantity at that time. Fig. 62 does not
illustrate setting below 30°C for the following reason.
That is, when the recording head temperature is equal
to or lower than 30°C, the sub-heaters are driven to
adjust the recording head temperature to be equal to or
10 higher than 30°C. The recording head temperature is
presumed by the temperature prediction control means
described in the 26th embodiment. When the recording
head temperature falls within the range of 30°C
(inclusive) and 36.25°C (exclusive), the recording head
15 is driven by PWM4 capable of obtaining the maximum
ejection quantity. When the recording head temperature
exceeds 36.25°C, the PWM value is switched to PWM3.
Thereafter, every time an increase in recording head
temperature exceeds 6.25°C, the PWM value is switched
20 in the order of PWM2 and PW1.

Operations upon execution of recording using the
recording apparatus with the above-mentioned
arrangement will be described below with reference to
the flow chart shown in Fig. 64.

25 When a print command is input in step S4000, the
recording head temperature is presumed (S4100). If the
recording head temperature is 30°C or less, the

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1 sub-heaters are driven in unit time to increase the
recording head temperature. Upon repetition of the
above operations, the recording head temperature is
adjusted to be 30°C or more (S4200 and S4300). If it
5 is determined in step S4200 that the recording head
temperature exceeds 30°C, the flow advances to step
S4400, and the rank of the PWM value is set based on
the recording head temperature. The pre-pulse width,
interval time, and main pulse width according to the
10 rank are obtained from Fig. 63, and a one-line print
operation is performed according to the obtained values
(S4500). Thereafter, the control returns to a print
standby state.

With the above-mentioned control, the upper limit
15 value of the ejection quantity controllable temperature
range of the recording head can be increased as
compared to the 27th embodiment. Since a temperature
difference between the recording head temperature and
the surrounding temperature is increased, the
20 temperature decrease speed of the recording head can
also be increased. Thus, even when the ejection
quantity controllable temperature range of the
recording head remains the same, an increase in
temperature of the recording head can be suppressed,
25 and the control range of the recording head temperature
with respect to input energy can be widened.

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1 In this embodiment, since four ranks of PWM values
are set, the allowable ejection quantity range is set
to be 5 pl. However, when the number of ranks of the
PWM values is increased, the allowable ejection
5 quantity range can be narrowed. In this embodiment,
the switching timing of the PWM values is set
immediately before the print operation of each line.
Alternatively, control may be made to switch the PWM
value a plurality of number of times during the
10 one-line print operation.

 In this embodiment, the control method of
increasing the temperature of the recording head to be
30°C or more using the sub-heaters is executed
immediately before printing. However, the sub-heaters
15 may be always driven even during printing. The optimal
increased/keeping temperature is determined by the
arrangement of the recording head, and the ink
composition, and is not limited to 30°C in this
embodiment. The arrangement and operations other than
20 the sub-heater driving control means are the same as
those in the above embodiment, and a detailed
description thereof will be omitted.

(29th Embodiment)

 The 29th embodiment for widening the control width
25 of the ejection quantity by PWM driving according to
the present invention will be described below.

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1 As described above, factors that limit the useable
temperature width of the recording head are two
factors, i.e., the ejection quantity control width of
PWM driving and the temperature dependency coefficient.
5 In the 28th embodiment, since the ejection quantity
change width is +30% (20 pl), and the temperature
dependency coefficient is 0.8, the useable temperature
range of the recording head is limited to 25°C (20
pl/0.8). Therefore, the lowest temperature of the
10 recording head is controlled to be 30°C or more using
the sub-heaters, thereby shifting the useable
temperature range (25°C) of the recording head toward
the upper limit side to attain effective control.

 However, in the control for driving the
15 sub-heaters immediately before recording, and disabling
the sub-heaters during printing, the print operation
must be waited until the recording head temperature is
increased to a predetermined temperature, i.e., 30°C.
As a result, the throughput (recording time) may be
20 decreased, and it is difficult to apply such control to
a product that requires high-speed operations. In
order to always drive the sub-heaters to control the
recording head temperature to be 30°C, the power supply
capacity capable of driving the sub-heaters during
25 printing is required, and this may cause an increase in
cost. In addition, the energy saving effect as the
primary object may be deteriorated.

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1 Thus, in the 29th embodiment, the useable
temperature range of the recording head is widened by
increasing the ejection quantity control width, thus
eliminating the above-mentioned influences upon the
5 rapid temperature rise of the recording head by, e.g.,
the sub-heaters, and a temperature keeping operation.

 This embodiment will be described in detail below.
In Fig. 53A, T1 represents a pre-pulse, T3 represents a
main pulse, and T2 represents an interval time between
10 the pre-pulse T1 and the main pulse T3. As has been
described in the above embodiment, the ejection
quantity can be controlled by changing T2 without
changing T1. Also, the ejection quantity can be
controlled by changing T1 without changing T2. Thus,
15 in this embodiment, both T1 and T2 are optimally
controlled according to the recording head temperature
to further widen the ejection quantity control width,
so that the useable temperature range of the recording
head can be widened without utilizing an external
20 assist means such as the sub-heaters.

 Fig. 65 shows the ratio of change in ejection
quantity when T1 and T2 are changed. As can be seen
from Fig. 65, when both T1 and T2 are changed, the
ejection quantity can be increased by 50% in this
25 embodiment. The pre-pulse T1 is used for the purpose
of increasing the ink temperature around ejection
heaters, and the ink temperature is increased to have a

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1 correlation with its pulse width. However, when the
pre-pulse T1 causes a bubble production phenomenon,
since a bubble may be irregularly produced upon
application of the main pulse, the upper limit of T1 is
5 determined by the maximum pulse width that does not
cause the bubble production phenomenon. Since the
pulse width of the pre-pulse T1 is left unchanged in
any environment in the 28th embodiment, the value T1 is
not set to be an upper limit value for the purpose of
10 energy saving and suppression of an increase in
temperature. However, this embodiment also controls T1
to provide the PWM effect with maximum efficiency.

In this embodiment, when the ink temperature is
15°C, $T1 = 3 \mu s$ that can attain the maximum ejection
15 quantity control width in Fig. 65 is set, thereby
realizing a maximum increase in ejection quantity (by
50%) in the 15°C environment. Since the ejection
quantity can be increased by 50% when the ink
temperature is at 15°C, and since the ejection quantity
20 change width is 28 pl ($85 - 85/1.5$), and the
temperature dependency coefficient is 0.8 in this
embodiment, the useable temperature range of the
recording head is inevitably set at 35°C ($28/0.8$).

With the above-mentioned control, the use range of
25 the recording head temperature, in which the ejection
quantity can be controlled to be an optimal ejection
quantity, can be widened to a range between 15°C and

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1 50°C (35°C width). The arrangement and operations
other than the pre-pulse width control means are the
same as those in the above embodiment, and a detailed
description thereof will be omitted.

5 As described above, in the multi-pulse PWM control
method of this embodiment, the duration of the OFF time
(interval time) between the first pulse (pre-pulse) and
the second pulse (main pulse) is set to be variable in
place of changing the width of the first pulse. More
10 specifically, heat efficiency is varied by changing the
heat conduction time with a minimum energy amount
without increasing the energy amount, and the degree of
activity of the ink at the interface between the heater
and the ink is changed, thus varying the ejection
15 quantity.

In this manner, the control range can be widened
without causing an increase in energy or a problem of
an increase in temperature, and without causing an
ejection error such as irregular bubble production that
20 may easily occur at the limit point, and damage to
heaters. Therefore, the ejection quantity can be
stably controlled without posing a problem of an
increase in power supply capacity or a problem of an
overload upon battery driving, or without forming wait
25 time even at a low temperature depending on the method.

Furthermore, when both the first pulse and the
interval time are independently controlled, the

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1 variable range of the ejection quantity can be greatly
widened. When the ink temperature is controlled also
using the sub-heaters, the controllable range can also
be widened.

5 Ejection is stabilized according to the ink
temperature in the ejection unit in the recording mode,
which is presumed prior to recording, thus obtaining a
high-quality image having a uniform density. Since the
ink temperature is presumed without providing a
10 temperature sensor to the recording head, the recording
apparatus main body and the recording head can be
simplified.

As described above, in the multi-pulse PWM control
method of the present invention, the duration of the
15 OFF time (interval time) between the first pulse
(pre-pulse) and the second pulse (main pulse) is set to
be variable in place of changing the width of the first
pulse. More specifically, heat efficiency is varied by
changing the heat conduction time with a minimum energy
20 amount without increasing the energy amount, and the
degree of activity of the ink at the interface between
the heater and the ink is changed, thus varying the
ejection quantity.

In this manner, the control range can be widened
25 without causing an increase in energy or a problem of
an increase in temperature, and without causing an
ejection error such as irregular bubble production that

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1 may easily occur at the limit point, and damaging
heaters.

(30th Embodiment)

5 In the method of varying the interval time between
the pulses described in the 29th embodiment, the
above-mentioned problems of, e.g., an increase in
temperature can be remarkably improved in principle.
However, the main pulse as a pulse for actually causing
ejection still has room for improvements. For example,
10 when the minimum driving period of the recording head
is shortened to increase the recording speed, since the
heat conduction characteristics of the members
themselves constituting the recording head approach
their limits, if any wasteful heat quantity that cannot
15 be converted into ejection energy is applied, local
heat accumulation occurs near ejection nozzles. For
this reason, a refill error occurs or a bubble cannot
satisfactorily disappear due to an extreme increase in
ejection quantity V_d , and the next successive bubble
20 production causes a bubble production error, resulting
in an ejection disable state.

When the interval time is further increased to
widen the ejection quantity controllable range, heat is
excessively diffused below the degree of activation
25 necessary for varying the ejection quantity, thus
decreasing heat efficiency. Even when the modulation
of the first pulse width and the modulation of the

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1 interval time are combined, a maximum of the ejection
quantity modulation width of about 50% can only be
obtained.

For this reason, the above-mentioned embodiment is
5 sufficient for the purpose of stabilizing the ejection
quantity, but is insufficient to obtain a halftone
image by varying the ejection quantity unless it is
combined with a large number of times of multi-scan
print operations.

10 The 30th embodiment of the present invention will
be described below.

At a simple low print ratio, the above-mentioned
result is obtained. However, when the print operation
is performed at a high print ratio, the heat efficiency
15 of the above-mentioned main pulse T3 (Fig. 53A) poses a
problem. Furthermore, when the minimum driving
ejection period (maximum driving frequency) is
shortened (increased) in, e.g., a high-speed mode in
units of print modes using a single head, the problem
20 of the heat efficiency cannot often be ignored. For
example, a difference shown in Fig. 66 is formed
between a case wherein the minimum ejection driving
period (maximum driving frequency) is 333 μ s (3 kHz)
and a case wherein the minimum ejection driving period
25 (maximum driving frequency) is 167 μ s (6 kHz).

Fig. 66 shows a change in temperature of the
recording head when the print operations are

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1 respectively performed at print ratios of 5% and 50%.
The print time is plotted along the abscissa.

The following description will be made mainly with
reference to Fig. 66 which best illustrates the
5 features of this embodiment. The graph shown in
Fig. 66 shows the degrees of temperature rise of the
recording head with respect to the print times when the
print operations are respectively performed at the
print ratios of 50% and 5% in the 27th and 30th
10 embodiments. In the 27th embodiment, the print
operation at the print ratio of 50% is performed to
have the main pulse width T3 of 7 μ sec, and that at the
print ratio 5% is performed to have the main pulse
width T3 of 3 μ sec. In these cases, the pre-pulse
15 width T1 is fixed to 3 μ sec, and the interval time T2
is varied. The minimum driving period of recording is
set to be 167 μ sec (high-speed mode) in this
embodiment, and a recording head, which has a thermal
limit in use of 333 μ sec in the conventional driving
20 technique, is used. More specifically, when this head
is used in driving of 167 μ sec, it causes an
overheating state in practice. In the latter half of
one line, ejection becomes unstable, and when several
lines are continuously printed, the ejection disable
25 state occurs at last.

As for the embodiment of the present invention,
Fig. 66 also shows data at the print ratios of 50% and

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1 5%. The pre-pulse width T1 is similarly fixed to be 3
μsec, and the interval time T2 is varied. The main
pulse width T3 is varied between 3 μsec and 7 μsec.
When the continuous print operation is performed in
5 this state, the head shows a change in temperature
shown in Fig. 66.

The possible ejection region of the main pulse T3
in the multi-pulse PWM driving mode is influenced by
the pre-pulse T1 and the interval time T2. The
10 influence of the interval time T2 will be described
first. In contrast to the single-pulse driving mode,
in the multi-pulse driving mode, since the temperature
at the interface between the heater and the ink
immediately before the main pulse is output is
15 maintained at a high activation level, a time after the
main pulse T3 is started until film boiling is started
is shortened, and as a result, the minimum necessary
pulse width of the main pulse T3 is shortened, as shown
in Fig. 67.

20 As has been described above with reference to
Figs. 55 and 56, in the multi-pulse PWM control based
on the interval time control method, input energy is
set to have a predetermined minimum value, and the
thickness (bubble production volume) of the ink layer
25 to be evaporated is controlled by the heat conduction
time after the pre-pulse T1 until the beginning of film
boiling.

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1 Furthermore, it is important that the thickness of
the ink layer capable of causing film boiling changes
during the interval time T2, and the time after the
main pulse T3 is started until film boiling is actually
5 started changes, as described above.

By utilizing these characteristics, when the main
pulse T3 is PWM-controlled in correspondence with a
change in interval time T2, wasteful energy which is
generated since a value at which bubble production and
10 ejection can be performed under the worst condition is
used although the film boiling start point changes can
be greatly decreased. More specifically, problems of,
e.g., the heat accumulation and overheating of the
recording head due to heating of the heaters in an
15 adiabatic state from the ink after film boiling is
already started, scorching and cavitation breakdown of
the ink due to an increase in heater peak temperature,
and the like, can be solved. Furthermore, since the
problem of heat accumulation can be remarkably
20 improved, the minimum driving period of the recording
head can be greatly prolonged. In particular, the
print operation at a high print ratio can be performed
in a driving frequency band in which such a print
operation is impossible so far. Fig. 68 shows an
25 actual change in pulse width when several lines at a
print ratio of 50% are printed on an A4-size recording
sheet.

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1 The influence of the pre-pulse T1 will be
explained below. In contrast to the single-pulse
driving mode, in the multi-pulse driving mode, since
the temperature at the interface between the heater and
5 the ink immediately before the main pulse is output is
maintained at a high activation level, a time after the
main pulse T3 is started until film boiling is started
is shortened, and as a result, the minimum necessary
pulse width of the main pulse T3 is shortened, as shown
10 in Fig. 69.

When the pre-pulse width T1 is changed, the same
temperature distribution as that obtained when the
interval time T2 is changed, as shown in Fig. 56, is
obtained. At this time, in the multi-pulse PWM control
15 based on the pre-pulse T1 control method, the ink
temperature at the interface between the heater and the
ink is controlled within a bubble non-production range
by varying input energy so as to vary the thickness
(bubble production volume) of the ink layer to be
20 evaporated, thereby controlling the ejection quantity.

In this case, it is important that the thickness
of the ink layer capable of causing film boiling
changes according to the pre-pulse width T1, and the
time after the main pulse T3 is started until film
25 boiling is actually started changes, as described
above.

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1 By utilizing these characteristics, when the main
pulse T3 is PWM-controlled in correspondence with a
change in pre-pulse width T1, wasteful energy which is
generated since a value at which bubble production and
5 ejection can be performed under the worst condition is
used although the film boiling start point changes can
be greatly decreased. More specifically, problems of,
e.g., the heat accumulation and overheating of the
recording head due to heating of the heaters in an
10 adiabatic state from the ink after film boiling is
already started, scorching and cavitation breakdown of
the ink due to an increase in heater peak temperature,
and the like, can be solved. Furthermore, since the
problem of heat accumulation can be remarkably
15 improved, the minimum driving period of the recording
head can be greatly prolonged. In particular, the
print operation at a high print ratio can be performed
in a driving frequency band in which such a print
operation is impossible so far. Fig. 70 shows an
20 actual change in pulse width when several lines at a
print ratio of 50% are printed on an A4-size recording
sheet.

As described above, in the method of this
embodiment, the main pulse width T3 is controlled to be
25 minimized according to changes in pre-pulse width T1
and in interval time T2 by utilizing a change in film
boiling start point of the main pulse T3 in the

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1 multi-pulse driving mode. Since the main pulse width
T3 is shortened, ejection can be performed by energy
about 70% that in the conventional method when the
maximum ejection quantity is obtained.

5 In an actual ejection quantity control method, a
temperature range described as "PWM control region" in
Fig. 57 is a temperature range in which the ejection
quantity can be stabilized. In this embodiment, this
temperature range corresponds to a range between 15°C
10 and 35°C of the ink temperature in the ejection unit.
Fig. 57 shows the relationship between the ink
temperature in the ejection unit and the ejection
quantity when the interval time is changed in 10 steps.
Even when the ink temperature in the ejection unit
15 changes, the ejection quantity can be controlled within
a width ΔV with respect to a target ejection quantity
Vd0 by changing the interval time at every temperature
step width ΔT according to the ink temperature.

(Temperature Prediction Control)

20 Operations in execution of recording using the
recording apparatus with the above arrangement will be
described below with reference to the flow charts shown
in Figs. 71 and 72.

Since steps S700 to S780 are the same as those in
25 Fig. 58, a detailed description thereof will be
omitted.

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1 The pre-pulse width T1 or the interval time T2 is
determined with reference to Figs. 61A and 61B for the
purpose of controlling the ejection quantity using the
PWM method (S890). The main pulse width T3 is
5 determined with reference to Fig. 73 or 74 according to
the pre-pulse width T1 or the interval time T2
determined in step S890 (S900).

Thereafter, since steps S910 to S960 are the same
as steps S800 to S850 in Fig. 59, a detailed
10 description thereof will be omitted.

In step S960, a difference (γ) between a print
target temperature (α) and a head chip temperature (β)
is calculated again. The pre-pulse value (the
pre-pulse width T1 or the interval time T2) for
15 printing the second area is obtained based on the
difference (γ) with reference to Figs. 61A and 61B, and
the pre-pulse value of the second area is set on a
memory (S970). In step S970, the main pulse width T3
is determined based on the pre-pulse width T1 or the
20 interval time T2 determined in step S970 with reference
to Fig. 73 or 74. (S980).

Thereafter, the power ratio in the corresponding
area is calculated based on the number of dots and the
pre-pulse value of the immediately preceding area,
25 thereby predicting the head chip temperature (β) at the
end of printing of the corresponding area. Then, the
pre-pulse value of the next area is set based on the

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1 difference (γ) between the print target temperature (α)
and the head chip temperature (β) (S930 to S980).
Thereafter, when the pre-pulse values for all the 10
areas in one line are set, the flow advances from step
5 S930 to step S990, and the sub-heaters are heated
before printing. Thereafter, the one-line print
operation is performed according to the set pre-pulse
values. Upon completion of the one-line print
operation in step S990, the flow returns to step S720
10 to read the temperature of a reference thermistor, and
the above-mentioned control operations are sequentially
repeated.

With the above-mentioned control, since the actual
ejection quantity can be stably controlled regardless
15 of the ink temperature, a high-quality recorded image
having a uniform density can be obtained.

(31st Embodiment)

The 31st embodiment of the present invention will
be described below. This embodiment pays attention to
20 the fact that the ejection possible minimum main pulse
width T3 in the single-pulse driving mode in the
recording head has dependency on the surrounding
temperature and the recording head temperature.
Fig. 75 shows the relationship between the temperature
25 of the recording head and the main pulse width that can
stably cause bubble production in the first ejection in
response to only a single pulse as the main pulse. As

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1 can be seen from Fig. 75, as the temperature is
decreased, the required pulse width is increased; when
the temperature is increased, the required pulse width
is decreased. In a range below the ejection possible
5 region, ejection becomes unstable, and the ejection
quantity is extremely decreased, resulting in a
splash-like printed state. When the temperature is
further decreased, ejection cannot be performed at all.
This value delicately changes depending on variations
10 of heads, contamination of heaters, and the like.

Therefore, in the single-pulse driving mode of
this embodiment, the pulse value is controlled by
directly measuring or predicting the temperature of the
recording head, thereby preventing the temperature of
15 the recording head from being excessively increased.

The control of the required pulse width based on
an increase in temperature of the recording head itself
is not to modulate the ejection quantity in real time
but to suppress heat that varies over a macroscopic
20 time, i.e., by the increase in temperature of the
recording head itself. For this reason, this control
is different in concept from control for changing the
pulse width of the recording head according to the
temperature of the recording head so as to obtain a
25 uniform density by density modulation in real time in,
e.g., a thermal transfer printer, a thermal printer,
and the like.

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1 Furthermore, the control of the main pulse width
for the macroscopic increase in temperature of the
recording head can also be applied to multi-pulse PWM
control.

5 When this concept is generalized, the control of
the main pulse is performed not only at a macroscopic
temperature, i.e., the temperature of the heater board
of the recording head, but also at a temperature
associated with the degree of activation at the
10 interface between the heater and the ink where film
boiling occurs, as described above. Since the
surrounding temperature and the increased temperature
of the recording head itself have a large difference
from a bubble production temperature, the pulse width
15 required for bubble production changes due to the
surrounding temperature or the increased temperature of
the recording head although the change is not so large.
In the apparatus for performing the multi-pulse PWM
control, as described in the 30th embodiment, the
20 temperature at the interface between the ink and the
heater changes according to the pre-pulse width T_1 , and
the degree of activation is increased very much, thus
considerably decreasing the minimum pulse width
necessary for bubble production.

25 As described above, in the 31st embodiment of the
present invention, in determination of the main pulse
value T_3 according to the temperature of the recording

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1 head, energy is further decreased as much as possible
by, e.g., multiplying a correction coefficient.

As described above, when the pre-pulse width T1 is
changed or when the interval time T2 is changed, the
5 temperature distribution shown in Fig. 56 is similarly
obtained. At this time, in the multi-pulse PWM control
based on the pre-pulse T1 control method, the ink
temperature at the interface between the heater and the
ink is controlled within a bubble non-production range
10 by varying input energy so as to vary the thickness
(bubble production volume) of the ink layer to be
evaporated, thereby controlling the ejection quantity.
In the multi-pulse PWM control based on the interval
time T2 control method, input energy is set to have a
15 predetermined minimum value, and the thickness of the
ink layer to be evaporated is controlled by the heat
conduction time after the pre-pulse T1 until the
beginning of film boiling.

In this case, it is important that the thickness
20 of the ink layer capable of causing film boiling
changes according to the pre-pulse width T1 and the
interval time T2, and the time after the main pulse T3
is started until film boiling is actually started
changes, as described above, and also changes according
25 to the ink tank temperature (equal to the surrounding
temperature) and the temperature of the recording head.

1 By utilizing these characteristics, when the main
pulse T3 is PWM-controlled in correspondence with
changes in pre-pulse width T1 and interval time T2,
which are multiplied with a correction coefficient
5 according to an increase in temperature, wasteful
energy supplied when the film boiling start point
changes according to the recording head temperature can
be further decreased. More specifically, problems of,
e.g., the heat accumulation and overheating of the
10 recording head due to heating of the heaters in an
adiabatic state from the ink after film boiling is
already started, scorching and cavitation breakdown of
the ink due to an increase in heater peak temperature,
and the like, can be solved. Furthermore, since the
15 problem of heat accumulation can be remarkably
improved, the minimum driving period of the recording
head can be further greatly prolonged. In particular,
the print operation at a high print ratio can be
performed in a driving frequency band in which such a
20 print operation is impossible so far.

 Figs. 76 and 77 show actual changes in main pulse
width T3 when the multi-pulse PWM control based on the
interval time T2 or pre-pulse T1 control method is
performed when several lines at a print ratio of 50%
25 are printed on an A4-size recording sheet.

 As described above, according to this embodiment,
the main pulse width T3 is controlled to be minimized

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1 according to a change in interval time T2 or pre-pulse
width T1 and the temperature of the recording head or
the surrounding temperature (= ink tank temperature) by
utilizing a change in film boiling start point of the
5 main pulse T3 in the multi-pulse driving mode. When
the main pulse width is changed according to the
surrounding temperature (= ink tank temperature), the
ink temperature is always lower than the temperature of
the recording head. For this reason, when the
10 temperature of the recording head is different from the
ink temperature in the common ink chamber or nozzles in
the recording head, another correction coefficient need
only be multiplied.

(32nd Embodiment)

15 Fig. 53B is a view for explaining divided pulses
according to the 32nd embodiment of the present
invention. In Fig. 53B, V_{OP} represents an operational
voltage, T11 and T13 represent the pulse widths of
pulses that do not cause bubble production (to be
20 referred to as pre-pulses hereinafter) of a plurality
of divided heat pulses, T12 and T14 represent interval
times, and T15 represents the pulse width of a pulse
that causes bubble production (to be referred to as a
main pulse hereinafter). These pulses have the same
25 functions as described in the 27th embodiment.

In this embodiment, the number of pre-pulses is
increased, as shown in Fig. 53B, to increase the energy

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1 amount to be applied to the ink, and PWM control of the
main pulse is added. Thus, a larger control range can
be obtained. Furthermore, in this embodiment, a case
will be explained below wherein the present invention
5 is applied not only to stabilization of the ejection
quantity but also to an ejection quantity modulation
method according to a halftone signal. In this
embodiment, a print operation can be performed even in
a region wherein overheating occurs due to an increase
10 in input energy, an increase in driving frequency, and
an increase in print ratio when the main pulse width T5
is not modulated.

In this embodiment, the pre-pulse widths T11 and
T13, and the interval times T12 and T14 between the
15 pre-pulses T11 and T13 and between the pre-pulse T13
and the main pulse T15 are varied to obtain the maximum
ejection quantity control range. According to this
method, the above-mentioned controllable range can be
greatly widened without causing overheating of the
20 recording head.

When the ejection quantity is controlled by the
structure of the recording head shown in Fig. 8 like in
the first embodiment, if the operational voltage $V_{OP} =$
22.0 (V) is set, and the main pulse width T15 is
25 changed between 1.000 and 4.000 [μ sec], the pre-pulse
widths T11 and T13 are changed between 0 and 3.000
[μ sec], and the interval times T12 and T14 are changed

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1 between 0 and 10 [μ sec] in combination to obtain a
linear change in ejection quantity, the characteristic
curve of the ejection quantity V_d [pl/drop] shown in
Fig. 78 is obtained.

5 Fig. 78 is a graph showing the pre-pulse width
dependency of the ejection quantity in this embodiment.
In Fig. 78, V_0 indicate the ejection quantity when T_{11}
to $T_{14} = 0$ [μ sec], and $T_{15} = 4$ [μ sec]. This value is
determined by the head structure shown in Fig. 8. In
10 this embodiment, $V_0 = 30.0$ [pl/drop] when the
surrounding temperature $T_R = 23^\circ\text{C}$. As indicated by the
curve in Fig. 78, the ejection quantity V_d is linearly
increased to a given region, and exhibits saturated
characteristics for a while. Thereafter, the ejection
15 quantity shows a slow descendant curve. In Fig. 78, a
practical maximum ejection quantity is 90 [pl/drop] in
the 23°C environment.

As described above, according to this embodiment,
when the ejection quantity is controlled by varying the
20 pre-pulse widths and the durations of the interval
times in the multi-pulse driving method, the main pulse
width is varied, i.e., is set to be a required minimum
value according to a change in film boiling start point
with respect to the main pulse upon changing of the
25 pre-pulse widths and the interval times, thereby
limiting heating of heaters in an adiabatic state from
the ink after film boiling is started, and preventing

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1 heat accumulation of the recording head, an increase in
heater peak temperature, scorching and cavitation
breakdown of the ink, and the like as much as possible.
Thus, the recording frequency can be greatly increased
5 due to the heat accumulation prevention effect of the
recording head.

According to this embodiment, the ejection
quantity control range can be greatly widened without
causing overheating of the recording head or causing an
10 ejection error such as irregular bubble production that
easily occurs at the limit point in the prior art and
damage to heaters, and without causing an increase in
power supply capacity, and a problem of the overload
upon battery driving. In addition, the ejection
15 quantity can be stably controlled without forming the
wait time even at low temperature depending a method.

Furthermore, when both the pre-pulse and the
interval time are independently controlled, the
variable range of the ejection quantity can be greatly
20 widened. When the ink temperature is controlled also
using the sub-heaters, the controllable range can also
be widened.

Ejection is stabilized according to the ink
temperature in the ejection unit in the recording mode,
25 which is presumed prior to recording, thus obtaining a
high-quality image having a uniform density. Since the
ink temperature is presumed without providing a

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1 temperature sensor to the recording head, the recording
apparatus main body and the recording head can be
simplified.

When the method of controlling the main pulse that
5 does not cause the recording head to accumulate heat is
used, the number of pulses per ejection, which do not
cause ejection, can be increased in practice.

Therefore, the ejection quantity modulation range can
be widened to a range which cannot be used in the prior
10 art, and halftone expression is allowed without
multi-scan operations or by a very small number of scan
operations.

Since heat accumulation is small, the minimum
driving period and solid black print continuity can be
15 remarkably improved as compared to the prior art.

The main pulse control in each of the above
embodiment may be performed in only the high-speed mode
when recording modes include the normal speed mode and
the high-speed mode shown in Fig. 66.

20 As described above, according to the present
invention, when the ejection quantity is controlled by
varying the pre-pulse widths and the durations of the
interval times in the multi-pulse driving method, the
main pulse width is varied, i.e., is set to be a
25 required minimum value according to a change in film
boiling start point with respect to the main pulse upon
changing of the pre-pulse widths and the interval

1 times, thereby limiting heating of heaters in an
adiabatic state from the ink after film boiling is
started, and preventing heat accumulation of the
recording head, an increase in heater peak temperature,
5 scorching and cavitation breakdown of the ink, and the
like as much as possible. Thus, the recording
frequency can be greatly increased due to the heat
accumulation prevention effect of the recording head.

The present invention brings about excellent
10 effects particularly in a recording head and a
recording device of the ink jet system using a thermal
energy among the ink jet recording systems.

As to its representative construction and
principle, for example, one practiced by use of the
15 basic principle disclosed in, for instance, U.S. Patent
Nos. 4,723,129 and 4,740,796 is preferred. The above
system is applicable to either one of the so-called
on-demand type and the continuous type. Particularly,
the case of the on-demand type is effective because, by
20 applying at least one driving signal which gives rapid
temperature elevation exceeding nucleus boiling
corresponding to the recording information on
electrothermal converting elements arranged in a range
corresponding to the sheet or liquid channels holding
25 liquid (ink), a heat energy is generated by the
electrothermal converting elements to effect film
boiling on the heat acting surface of the recording

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1 head, and consequently the bubbles within the liquid
(ink) can be formed in correspondence to the driving
signals one by one. By discharging the liquid (ink)
through a discharge port by growth and shrinkage of the
5 bubble, at least one droplet is formed. By making the
driving signals into pulse shapes, growth and shrinkage
of the bubble can be effected instantly and adequately
to accomplish more preferably discharging of the liquid
(ink) particularly excellent in accordance with
10 characteristics. As the driving signals of such pulse
shapes, the signals as disclosed in U.S. Patent
Nos. 4,463,359 and 4,345,262 are suitable. Further
excellent recording can be performed by using the
conditions described in U.S. Patent No. 4,313,124 of
15 the invention concerning the temperature elevation rate
of the above-mentioned heat acting surface.

As a construction of the recording head, in
addition to the combined construction of a discharging
orifice, a liquid channel, and an electrothermal
20 converting element (linear liquid channel or right
angle liquid channel) as disclosed in the above
specifications, the construction by use of U.S. Patent
Nos. 4,558,333 and 4,459,600 disclosing the
construction having the heat acting portion arranged in
25 the flexed region is also included in the invention.
The present invention can be also effectively
constructed as disclosed in JP-A-59-123670 which

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1 discloses the construction using a slit common to a
plurality of electrothermal converting elements as a
discharging portion of the electrothermal converting
element or JP-A-59-138461 which discloses the
5 construction having the opening for absorbing a
pressure wave of a heat energy corresponding to the
discharging portion.

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CLAIMS:

1. A temperature calculation method for predicting a change in temperature of an object, which varies according to input energy, comprising the steps of:

supplying input energy to said object;

determining elapse of unit times;

obtaining, as discrete values, changes in temperature of said object upon the elapse of unit time based on the energy input to said object per every unit time;

storing the discrete values obtained in said obtaining step; and

accumulating discrete values stored in said storing step upon elapse of the unit times to calculate the change in temperature of said object.

2. A method according to claim 1, wherein said obtaining step obtains the discrete value using a calculation table, which is obtained by calculating the change in temperature of said object upon elapse of unit time in advance within a range of possible input energy.

3. A method according to claim 2, wherein said calculation table used in said obtaining step comprises a two-dimensional matrix of input energy in unit time and an elapsed time.

4. A method according to claim 1, wherein said object comprises a recording head whose temperature varies according to the input energy.

5. A method according to claim 4, further comprising the step of controlling said recording head based on the change in temperature calculated in said accumulating step.

6. A recording apparatus comprising:

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a recording head having an ejection unit and performing recording by ejecting ink from said ejection unit using heat energy;

temperature measuring means for measuring a temperature in a surrounding area of said recording head;

supplying means for supplying energy to said recording head;

determining means for determining elapse of unit times;

obtaining means for obtaining, as discrete values, changes in temperature of said recording head upon the elapse of unit time based on a thermal time constant of said recording head, and energy supplied to said recording head in a reference period;

storing means for storing the discrete values obtained by said obtaining means;

accumulating means for accumulating corresponding discrete values stored by said storing means upon the elapse of unit times;

calculating means for calculating the change in temperature of said recording head based on the discrete values accumulated by said accumulating means;

temperature presuming means for presuming the temperature of said recording head based on the change in temperature calculated by said calculating means and the surrounding temperature measured by said temperature measuring means; and

ejection quantity control means for controlling an ejection quantity of the ink ejected from said ejection unit based on the temperature presumed by said temperature presuming means.

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7. An apparatus according to claim 6, wherein said recording head causes a change in state in the ink by heat energy, and ejects the ink perforce of the change in state.

8. An apparatus according to claim 6, wherein a driving signal is applied to said recording head and said ejection quantity control means changes the driving signal supplied to said recording head based on the presumed temperature.

9. An apparatus according to claim 8, wherein said driving signal has a pre-heat pulse and a main heat pulse, and said ejection quantity control means changes a pulse width of said pre-heat pulse on the basis of the predicted temperature.

10. A recording apparatus using a recording head constituted by combining a plurality of members having different heat conduction times, and causing a change in temperature upon execution of recording comprising:

energy input means for inputting energy to said recording head;

determining means for determining elapse of unit times;

modeling means for modeling said recording head using a plurality of thermal time constants; and

storing means for storing the plurality of thermal time constants used by said modeling means;

temperature calculation means for calculating the change in temperature of said recording head in correspondence with the stored thermal time constants based on energy input to said recording head per the elapse of unit time.

11. An apparatus according to claim 10, wherein said modeling means models said recording head using a smaller number of thermal time

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constants than an actual number of thermal time constants of said recording head.

12. An apparatus according to claim 10, further comprising calculation algorithm means for performing calculations while grouping required calculation intervals and required data hold times in units of models.

13. An apparatus according to claim 12, wherein said calculation algorithm means sets a plurality of heat sources, calculates temperature rise widths in units of the models for each of said plurality of heat sources, and adds the temperature rise widths to calculate a head temperature.

14. An apparatus according to claim 10, further comprising:
surrounding temperature measuring means for measuring a temperature in a surrounding area of said recording head; and
control means for controlling said recording head based on the surrounding temperature measured by said surrounding temperature measuring means, and the change in temperature calculated by said temperature calculation means.

15. A recording apparatus comprising:
a recording head having an ejection unit an performing recording by ejecting ink from said ejection unit using heat energy;
temperature measuring means for measuring a temperature in a surrounding area of said recording head;

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supplying means for supplying energy to said recording head;

determining means for determining elapse of unit times;

5 obtaining means for obtaining, as discrete values, changes in temperature of said recording head upon the elapse of unit time based on a thermal time constant of said recording head, and energy supplied to said recording head in a reference period;

10 storing the discrete values obtained by said obtaining means;

accumulating means for accumulating corresponding discrete values stored by said storing means upon elapse of unit times;

15 calculating means for calculating the change in temperature of said recording head based on the discrete values accumulated by said accumulating means;

presuming means for presuming the temperature of said recording head based on the change in temperature
20 calculated by said calculating means and the surrounding temperature measured by said temperature measuring means;
and

ejection stabilization control means for performing ejection stabilization control according to the
25 temperature of the recording head presumed by said presuming means.

16. An apparatus according to claim 15, wherein said ejection stabilization control means performs
30 recovery processing of said recording head under a condition according to the predicted temperature.

17. An apparatus according to claim 15, wherein said ejection stabilization control means performs pre-
35 ejection of said recording head under a condition

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according to the predicted temperature.

18. An apparatus according to claim 15, wherein said ejection stabilization control means comprises means for determining whether or not suction recovery of said recording head should be performed, on the basis of the predicted temperature, and said ejection stabilization control means performs a suction recovery control on the basis of a determination result of said determination means.

19. An apparatus according to claim 15, wherein said ejection stabilization control means performs temperature control of said recording head under a condition according to the predicted temperature.

20. An apparatus according to claim 15, wherein said recording head causes a change in state in the ink by heat energy, and ejects the ink perforce of the change in state.

21. A recording apparatus comprising:
a recording head having an ejection unit and performing recording by ejecting ink from said ejection unit using heat energy;
temperature measuring means for measuring a temperature in a surrounding area of said recording head;
supplying means for supplying signals to said recording head to cause said recording head to record at a drive duty;
determining means for determining elapse of unit times;
obtaining means for obtaining, as discrete values, changes in temperature of said recording head upon the elapse of unit time based on a thermal time constant of said recording head, and the drive duty of said recording head;
storing means for storing the discrete values obtained by said obtaining means;

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accumulating means for accumulating corresponding discrete values stored by said storing means upon elapse of unit times;

calculating means for calculating the change in
5 temperature of said recording head based on the discrete values accumulated by said accumulating means;

temperature presuming means for presuming the temperature of said recording head based on the change in temperature calculated by said calculating means and the
10 surrounding temperature measured by said temperature measuring means; and

ejection quantity control means for controlling an ejection quantity of the ink ejected from said ejection unit based on the temperature presumed by said
15 temperature presuming means.

22. A recording apparatus using a recording head constituted by combining a plurality of members having different heat conduction times, and causing a change in
20 temperature upon execution of recording, comprising:

energy input means for inputting energy to said recording head to cause said recording head to record at a drive duty;

modeling means for modeling said recording head
25 using a plurality of thermal time constants; and

storing means for storing the plurality of thermal time constants used by said modeling means;

temperature calculation means for calculating the change in temperature of said recording head in
30 correspondence with the stored thermal time constants based on the drive duty of said recording head.

23. A recording apparatus comprising:

a recording head having an ejection unit and
35 performing recording by ejecting ink from said ejection

- 200 -

unit using heat energy;

temperature measuring means for measuring a temperature in a surrounding area of said recording head;

supplying means for supplying signals to said recording head to cause said recording head to record at a drive duty;

determining means for determining elapse of unit times;

obtaining means for obtaining, as discrete values, changes in temperature of said recording head upon the elapse of unit time based on a thermal time constant of said recording head, and the drive duty of said recording head;

storing means for storing the discrete values obtained by said obtaining means;

accumulating means for accumulating corresponding discrete values stored by said storing means upon the elapse of unit times;

calculating means for calculating the change in temperature of said recording head based on the discrete values accumulated by said accumulating means;

presuming means for presuming the temperature of said recording head based on the change in temperature calculated by said calculating means and the surrounding temperature measured by said temperature measuring means; and

ejecting stabilization control means for performing ejection stabilization control according to the temperature of the recording head presumed by said presuming means.

24. An apparatus according to claim 15, wherein said ejection stabilization means modulates the at least one pre-pulse for heating without causing ejection of ink, a main pulse for ejecting ink, and an interval of time indicating a period between the main pulse and the pre-pulse based on a table defining pulse conditions to ink temperatures, when the detected ink temperature is higher than the predetermined temperature.

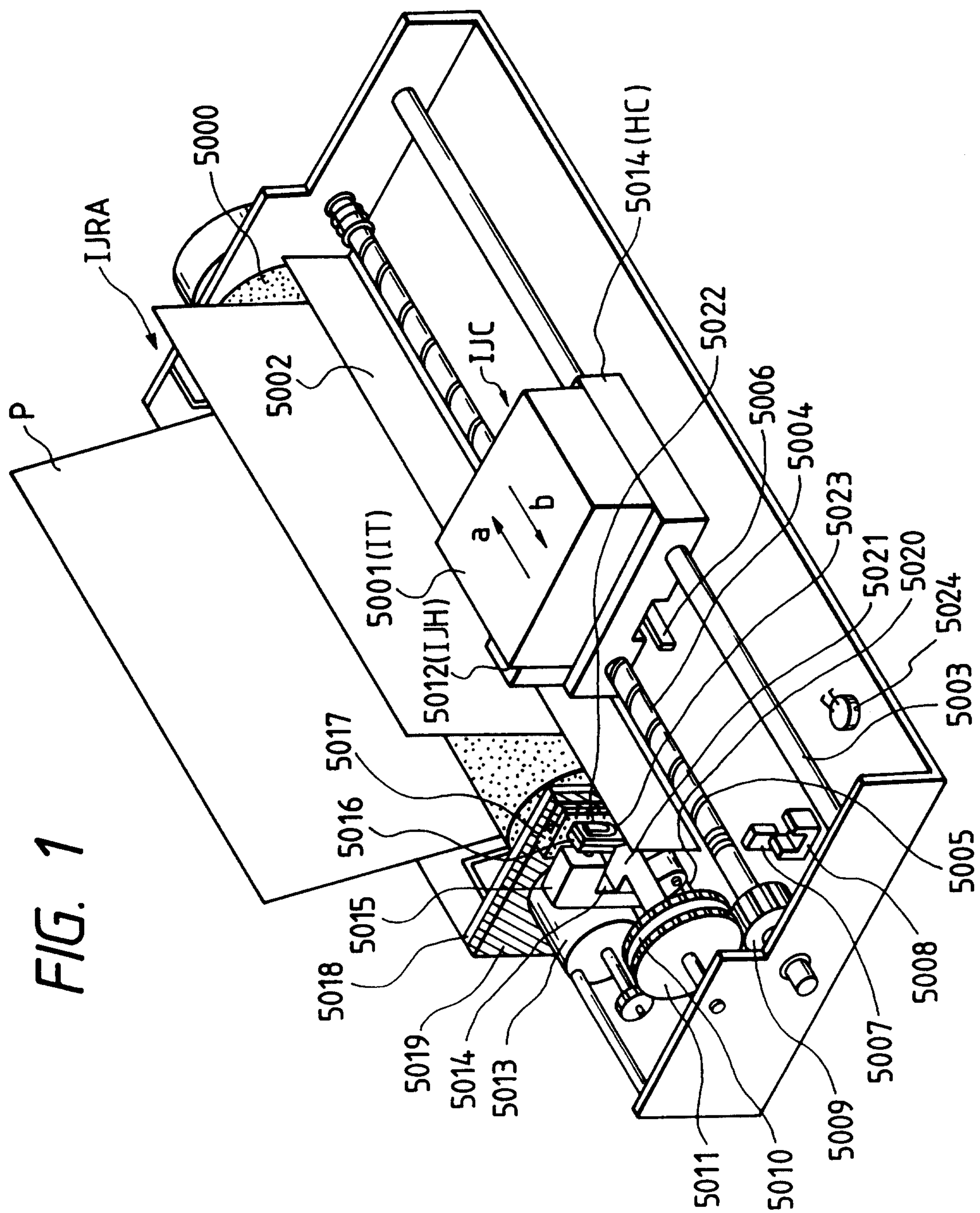


FIG. 1

FIG. 2

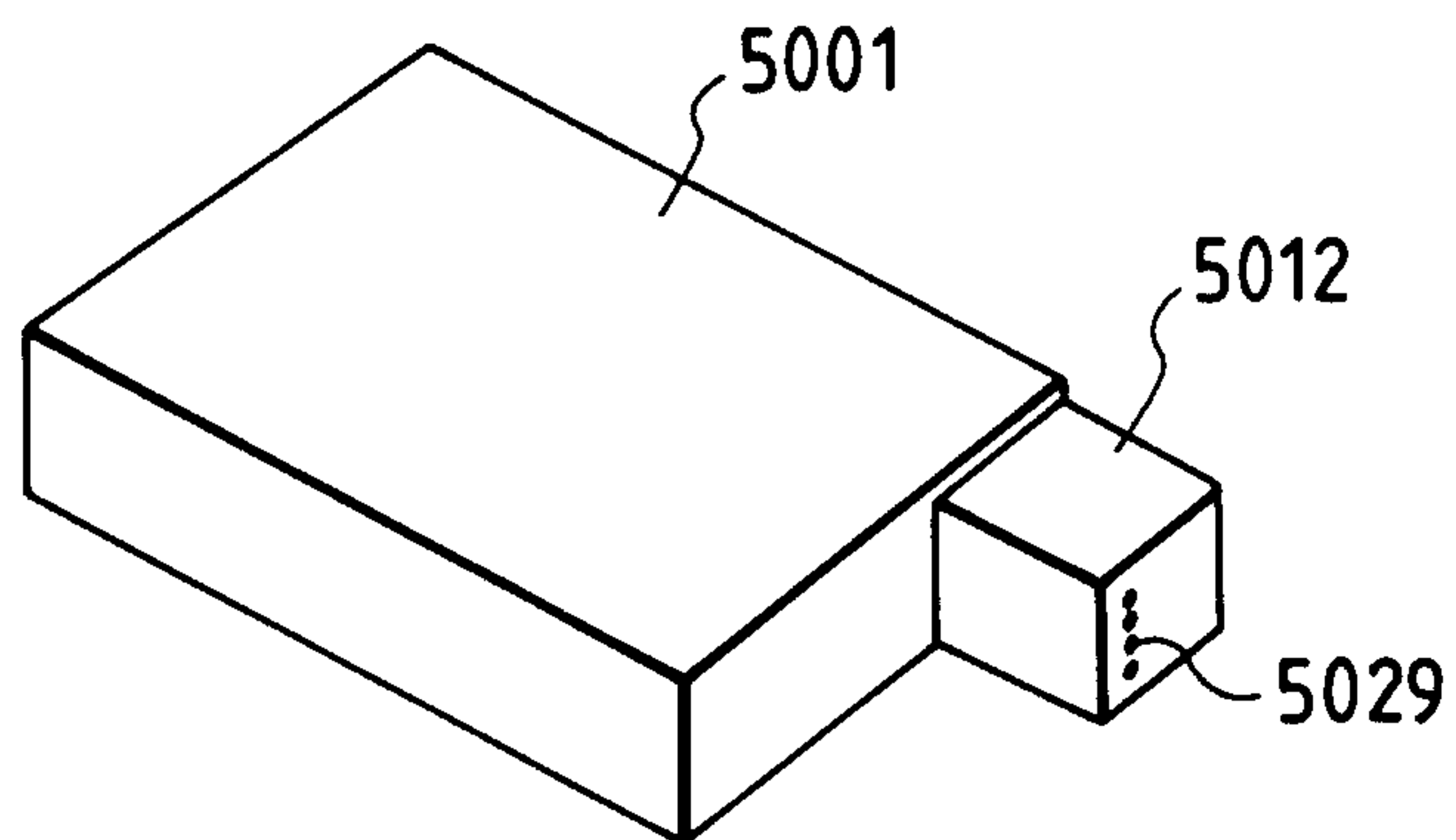
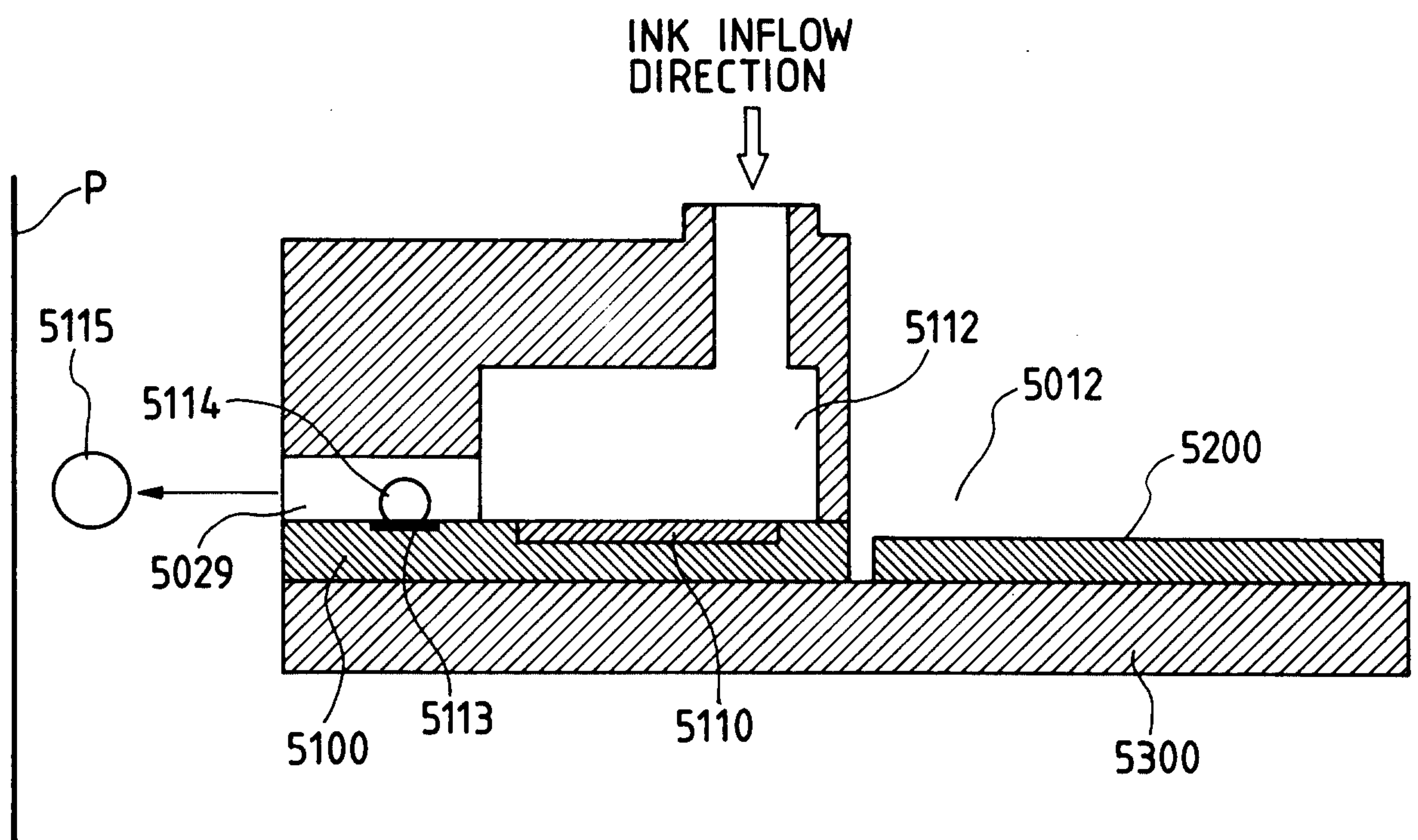


FIG. 3



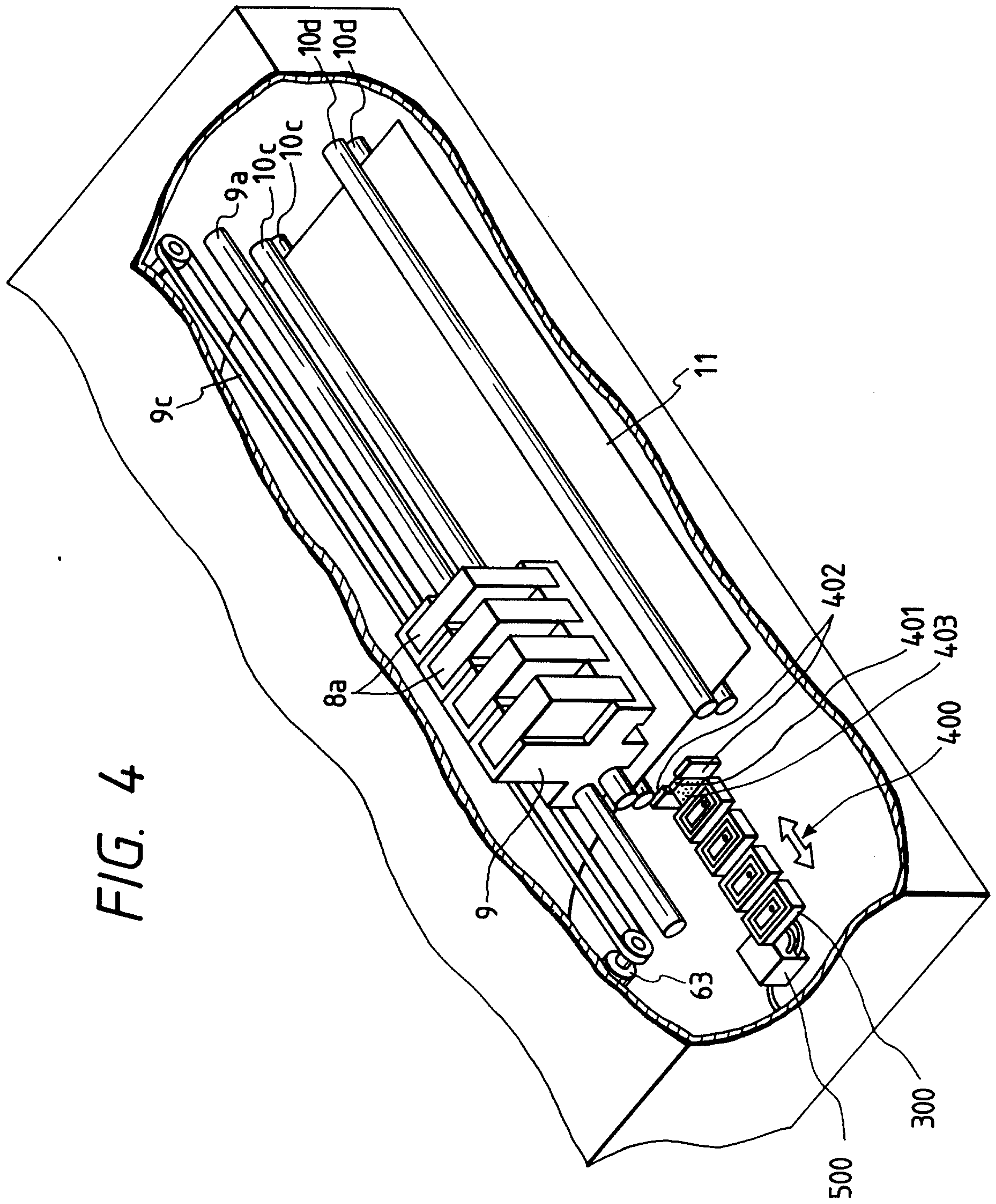


FIG. 4

FIG. 5

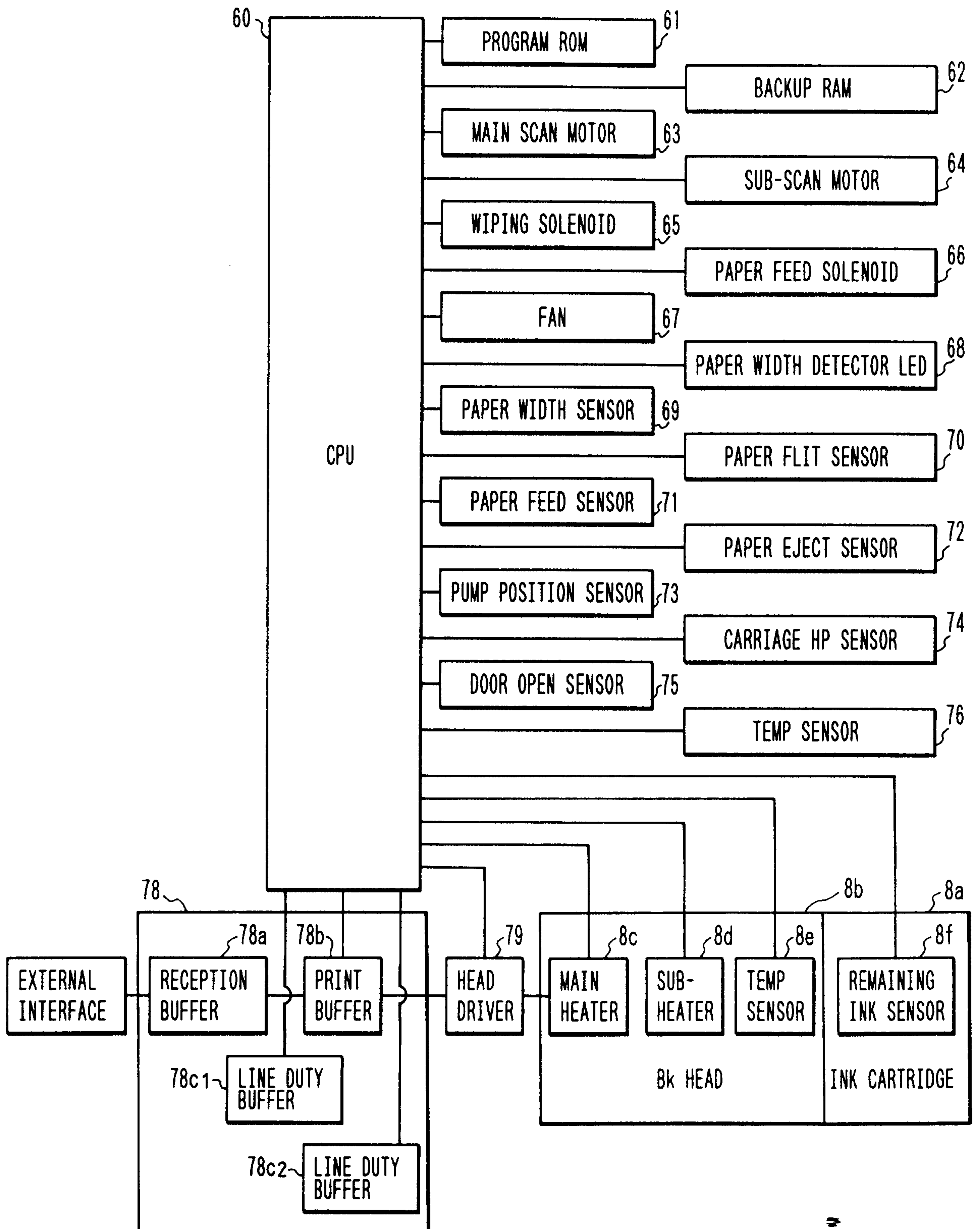


FIG. 6

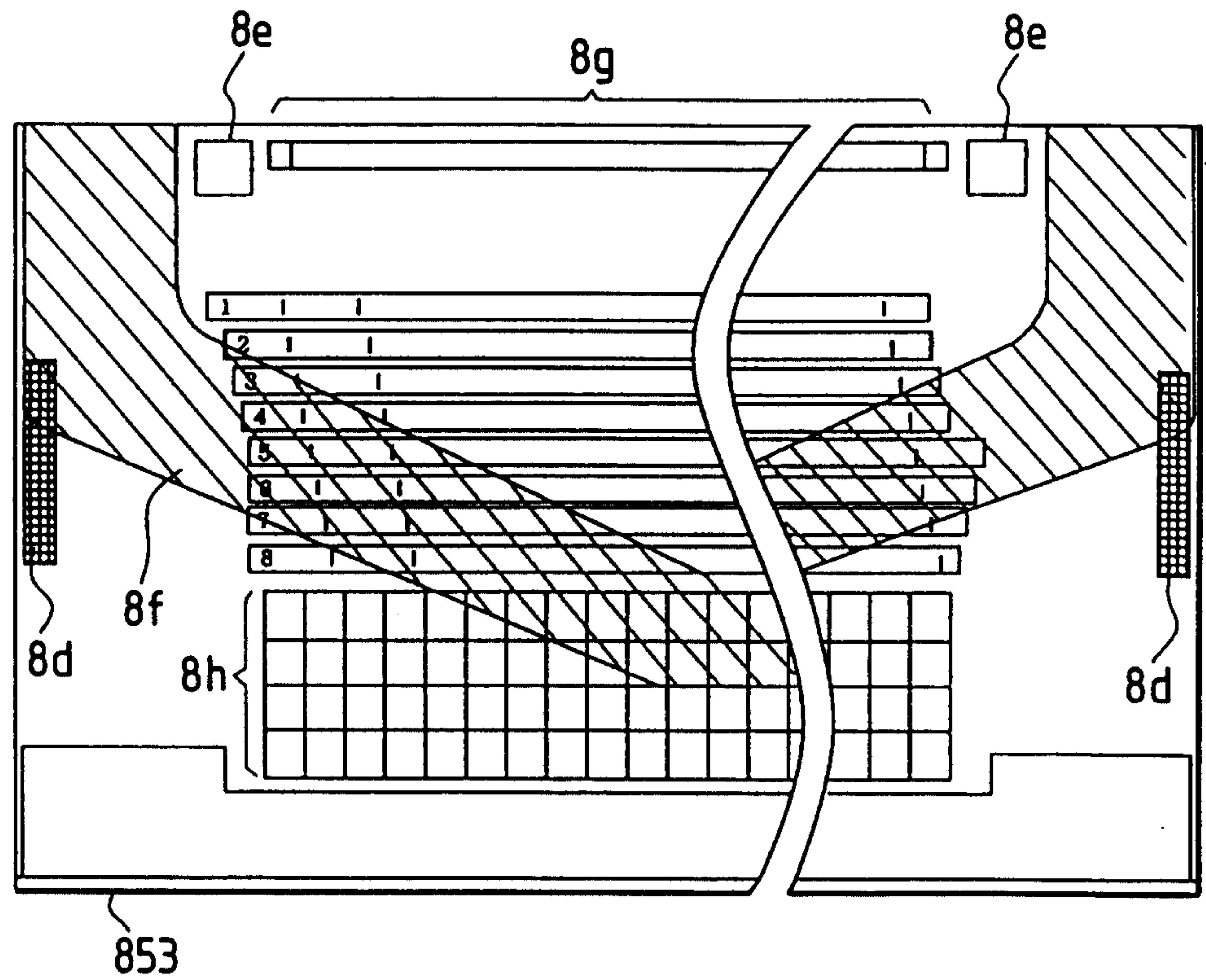
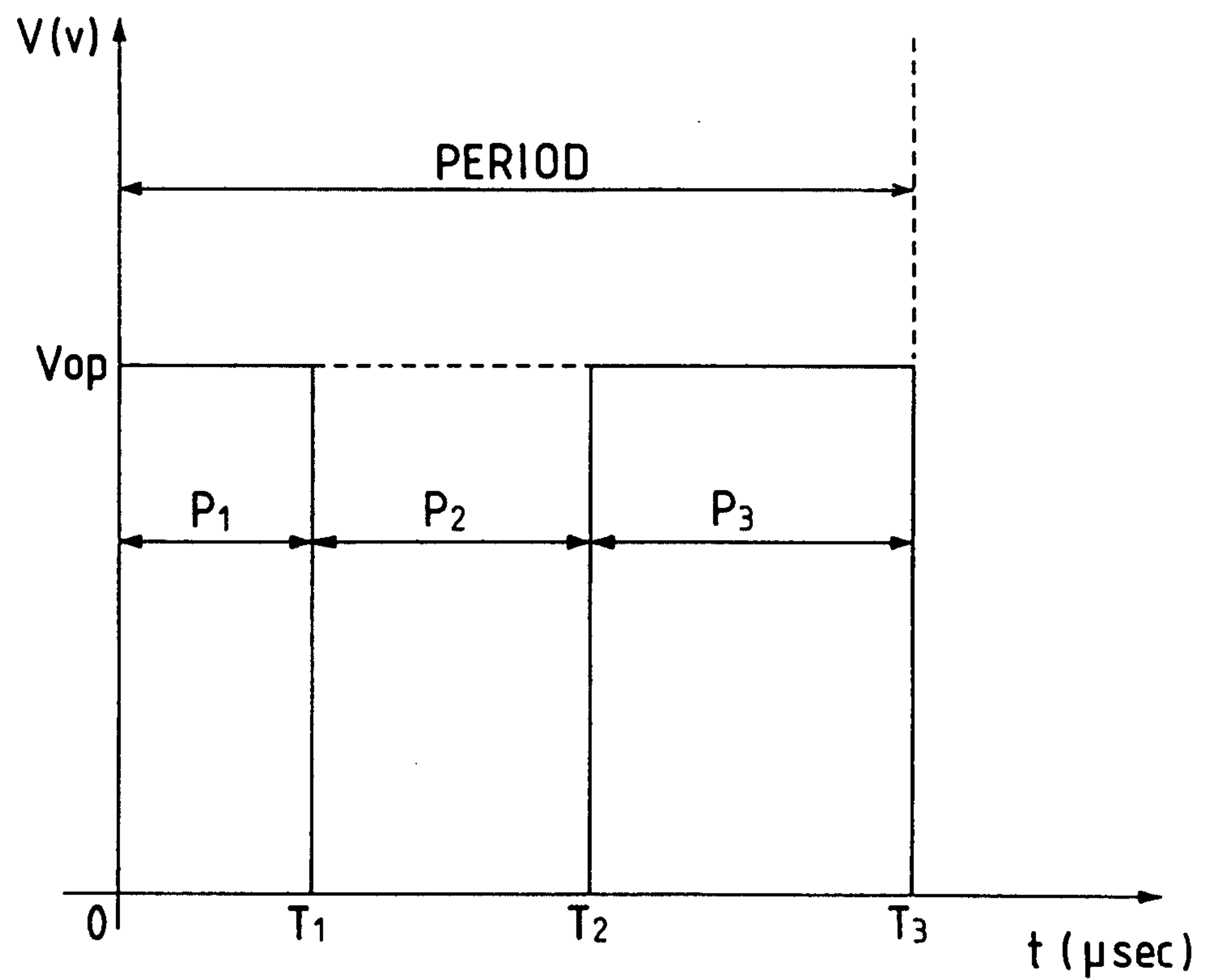


FIG. 7



P_1 : PRE-PULSE ($= T_1$) (PWM)
 P_2 : INTERVAL ($= T_2 - T_1$)
 P_3 : MAIN PULSE ($= T_3 - T_2$)
 V_{op} : OPERATIONAL VOLTAGE

FIG. 8A

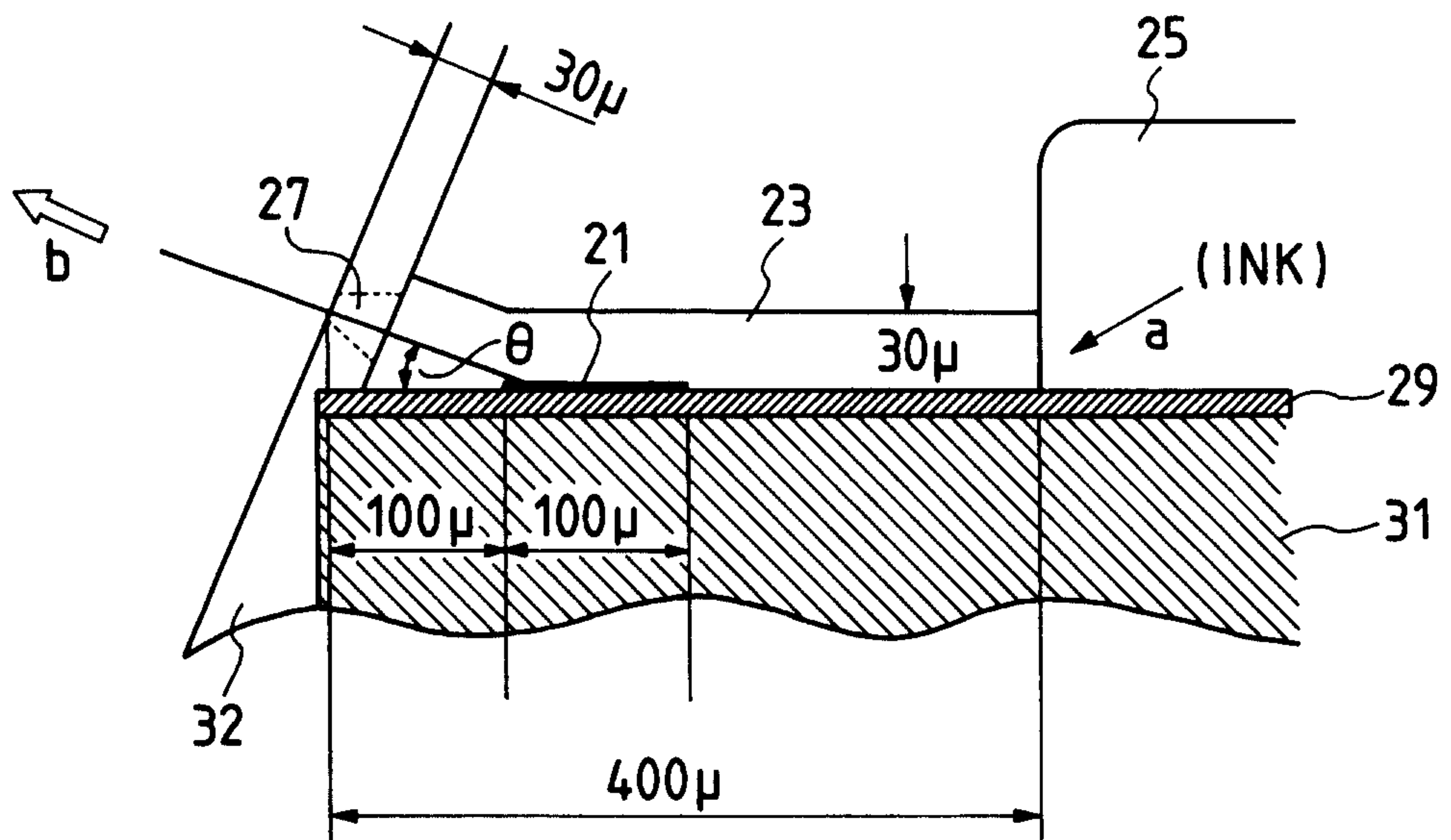


FIG. 8B

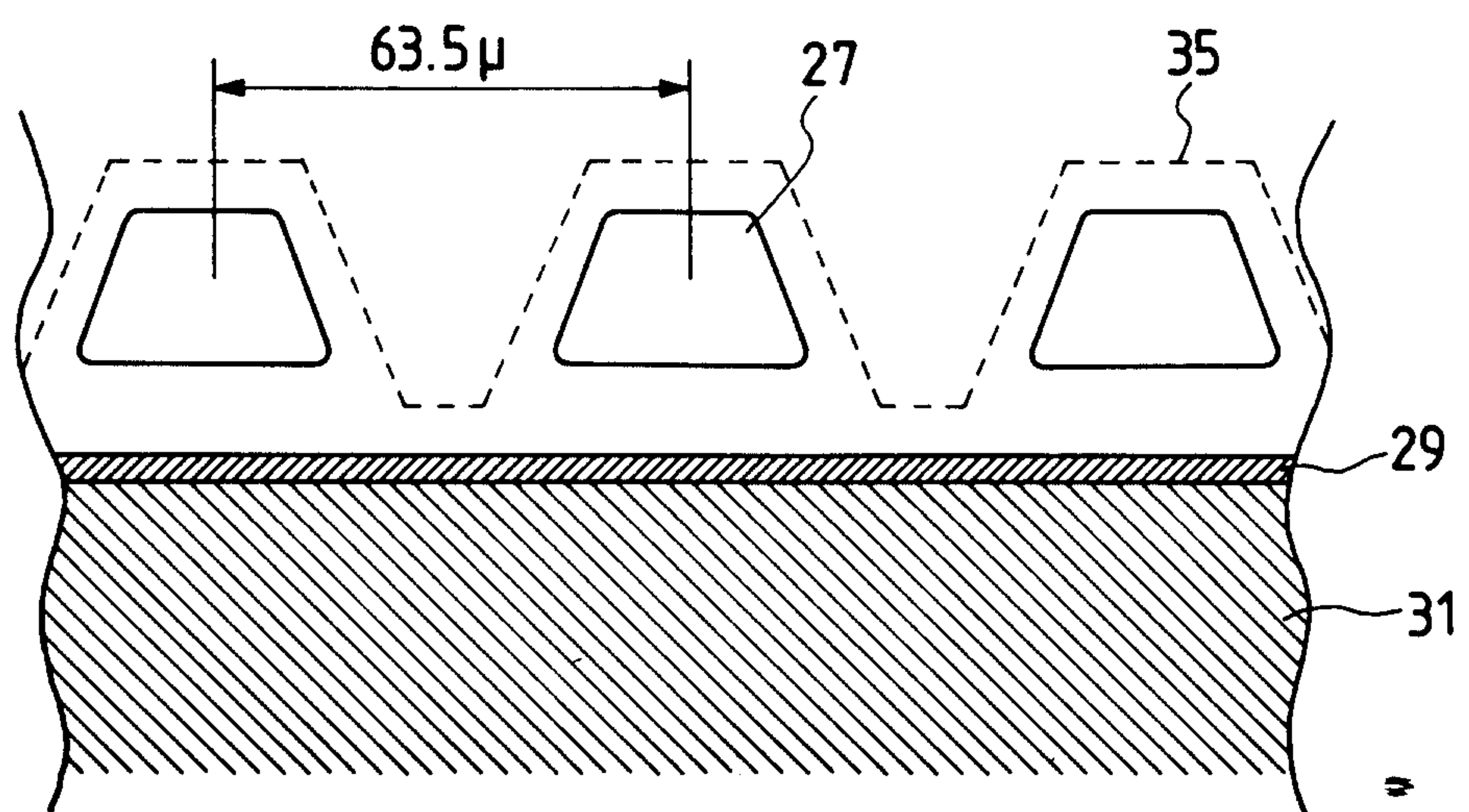


FIG. 9

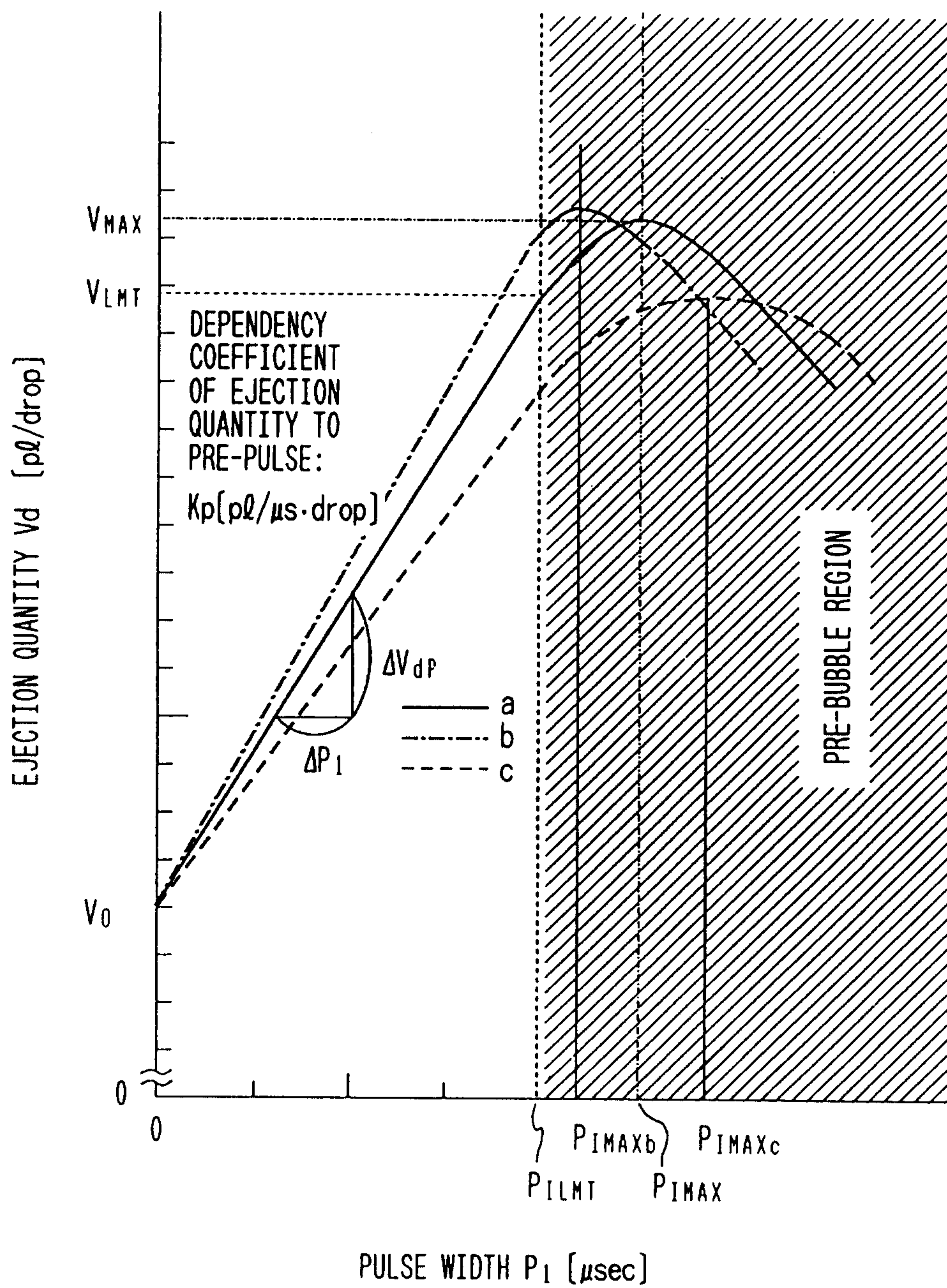


FIG. 10

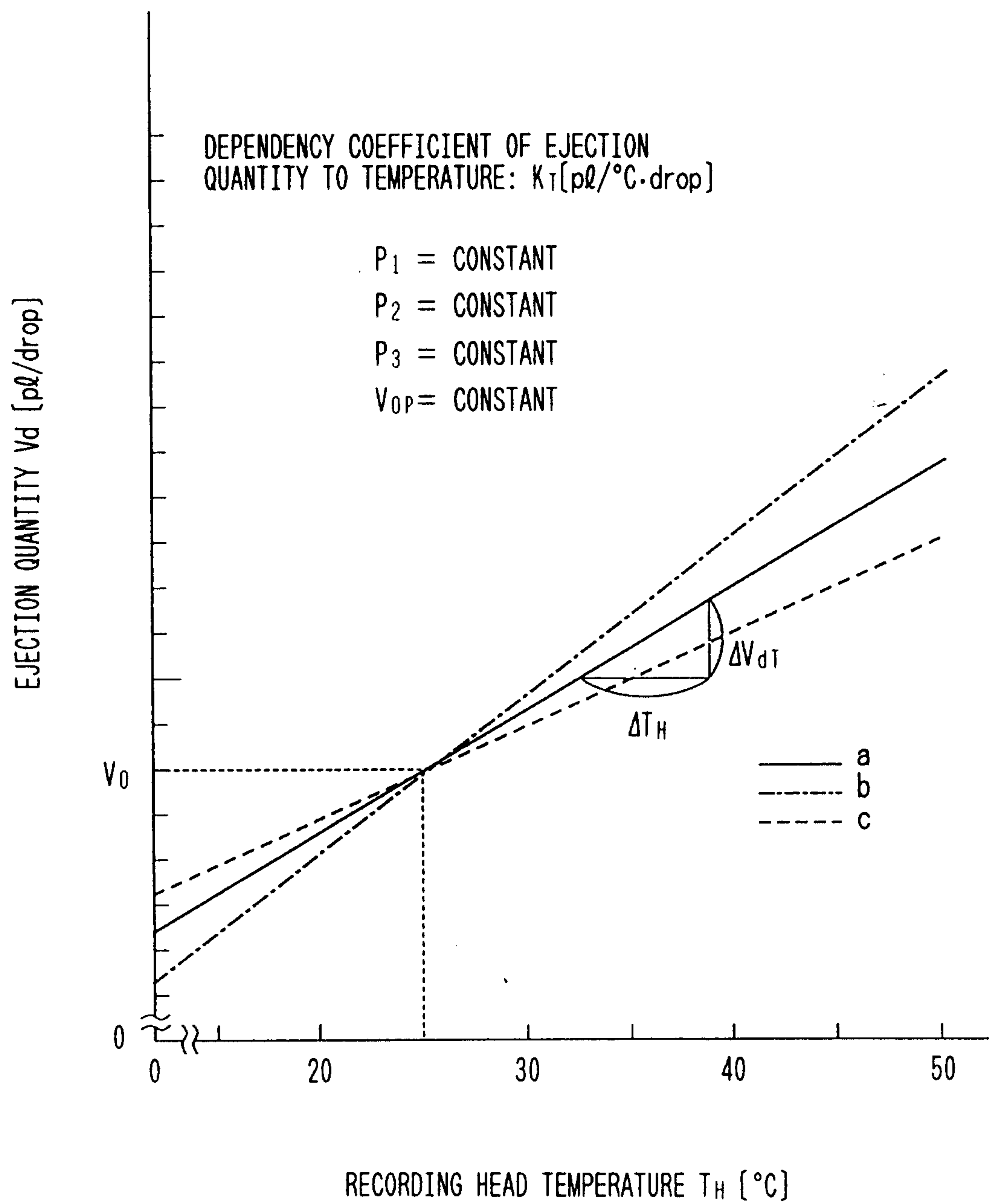


FIG. 11

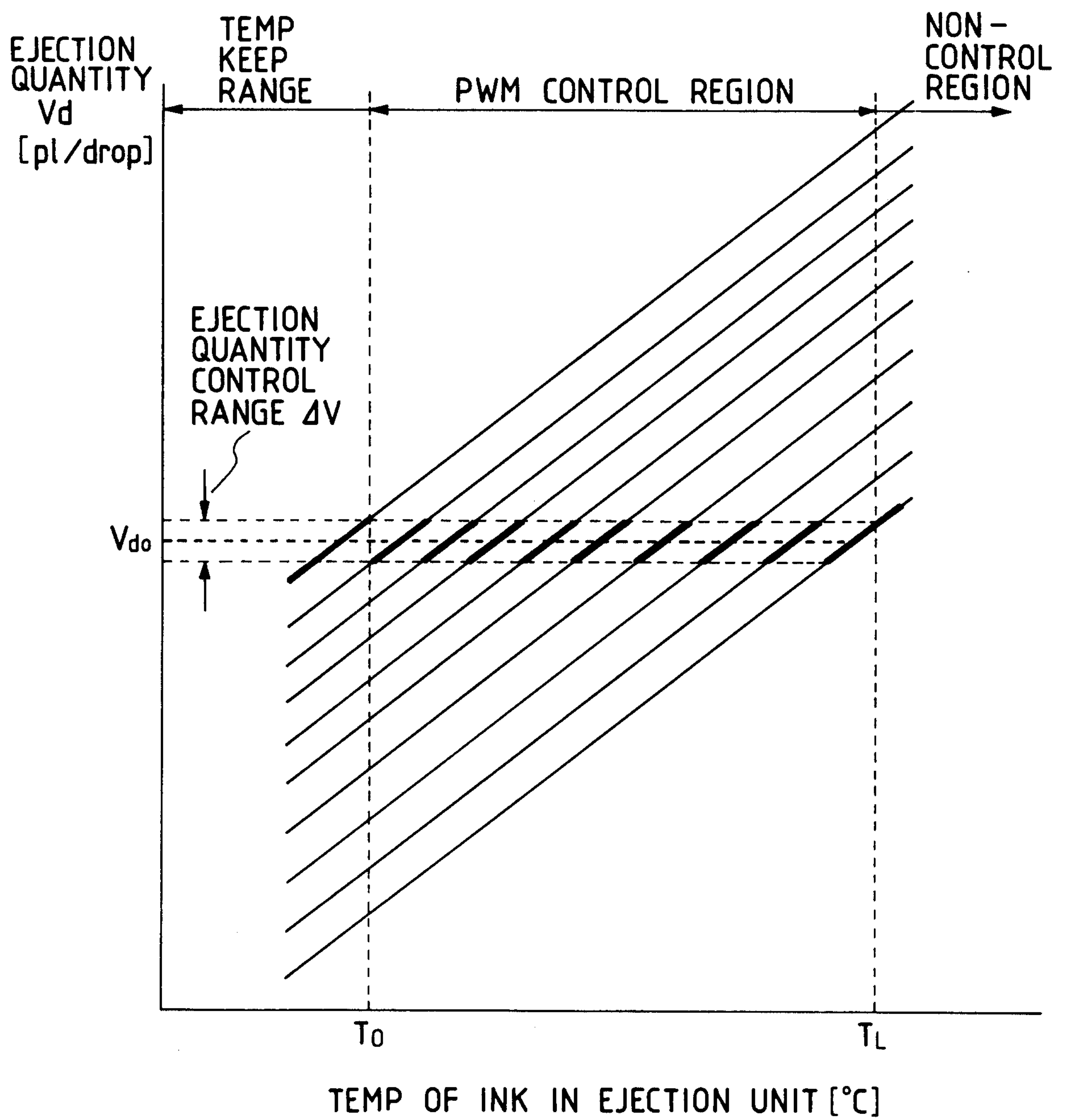


FIG. 12A

INK TEMP-PREPULSE TABLE (1)

PREPULSE NO.	1	2	3	4	5	6	7	8	9	10	11
INK TEMP [°C]	<36	36 ~ 38	38 ~ 40	40 ~ 42	42 ~ 44	44 ~ 46	46 ~ 48	48 ~ 50	50 ~ 52	52 ~ 54	≥54
PREPULSE WIDTH [μsec]	1.87	1.68	1.49	1.31	1.12	0.93	0.75	0.56	0.37	0.19	0.19

FIG. 12B

INK TEMP-PREPULSE TABLE (2)

PREPULSE NO.	1	2	3	4	5	6	7	8	9	10	11
INK TEMP [°C]	<36	36 ~ 38	38 ~ 40	40 ~ 42	42 ~ 44	44 ~ 46	46 ~ 48	48 ~ 50	50 ~ 52	52 ~ 54	≥54
PREPULSE WIDTH [μsec]	2.05	1.87	1.68	1.49	1.31	1.12	0.93	0.75	0.56	0.37	0.19

FIG. 12C

INK TEMP-PREPULSE TABLE (3)

PREPULSE NO.	1	2	3	4	5	6	7	8	9	10	11
INK TEMP [°C]	<36	36 ~ 38	38 ~ 40	40 ~ 42	42 ~ 44	44 ~ 46	46 ~ 48	48 ~ 50	50 ~ 52	52 ~ 54	≥54
PREPULSE WIDTH [μsec]	1.68	1.49	1.31	1.12	0.93	0.75	0.56	0.37	0.19	0.19	0.19

FIG. 13

DESCENT TEMP TABLE
(INCREASED TEMP REMAINDER TO REF TEMP) UNIT $\times 10^{-3}$ deg

ELAPSE TIME (sec)	POWER RATIO DURING REF TIME PERIOD (%)									
	~10	~20	~30	~40	~50	~60	~70	~80	~90	~100
0.02	50	100	150	200	③ 250	300	350	400	450	500
0.04	46	93	139	184	230	277	322	⑥ 369	416	462
0.06	43	④ 85	128	170	212	256	297	341	384	426
0.08	39	79	119	157	196	236	275	314	354	394
0.10	36	73	109	145	181	218	253	290	327	363
0.12	33	67	101	134	167	201	234	268	302	335
0.14	31	62	93	123	154	186	216	247	279	310
0.16	29	57	86	114	142	171	199	228	258	286
0.18	26	53	79	105	132	158	184	211	238	264
0.20	24	49	73	97	121	146	170	194	219	244
0.22	22	45							202	225
5.04	0	0	0	0	0	0	0	0	1	
5.06	0	0	0	0	0	0	0	0	0	1
5.08	0	0	0	0	0	0	0	0	0	1
5.10	0	0	0	0	0	0	0	0	0	1
5.12	0	0	0	0	0	0	0	0	0	0

FIG. 14A

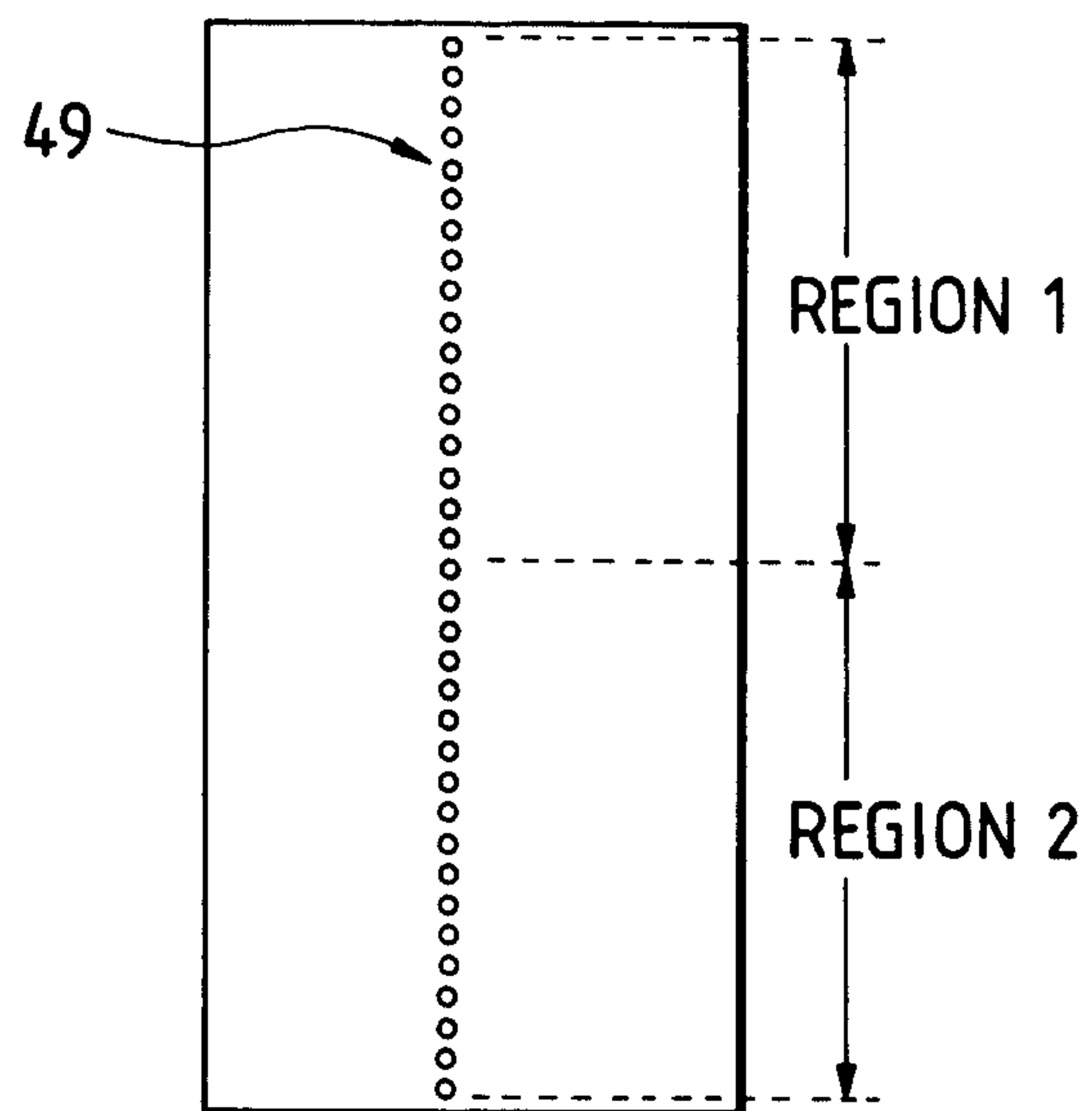


FIG. 14B

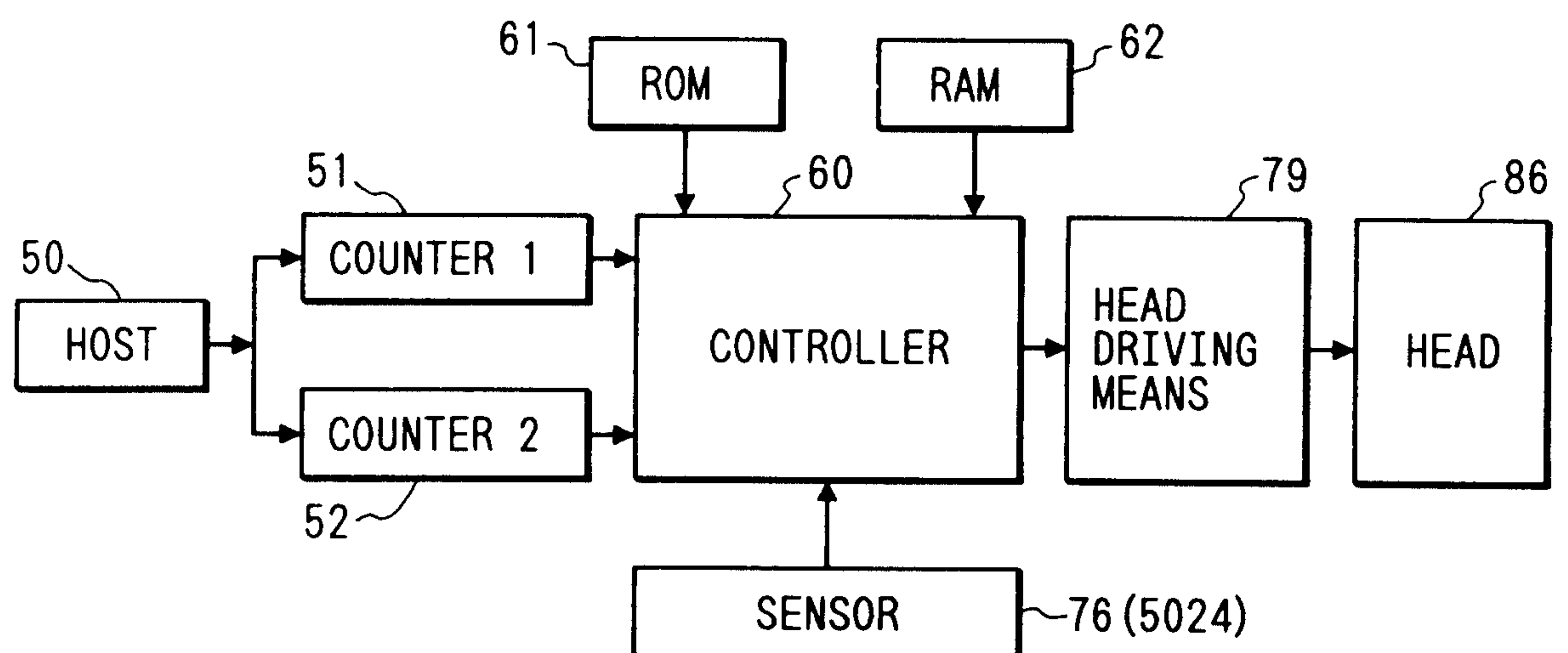


FIG. 15

FIG. 15A

FIG. 15B

FIG. 15A

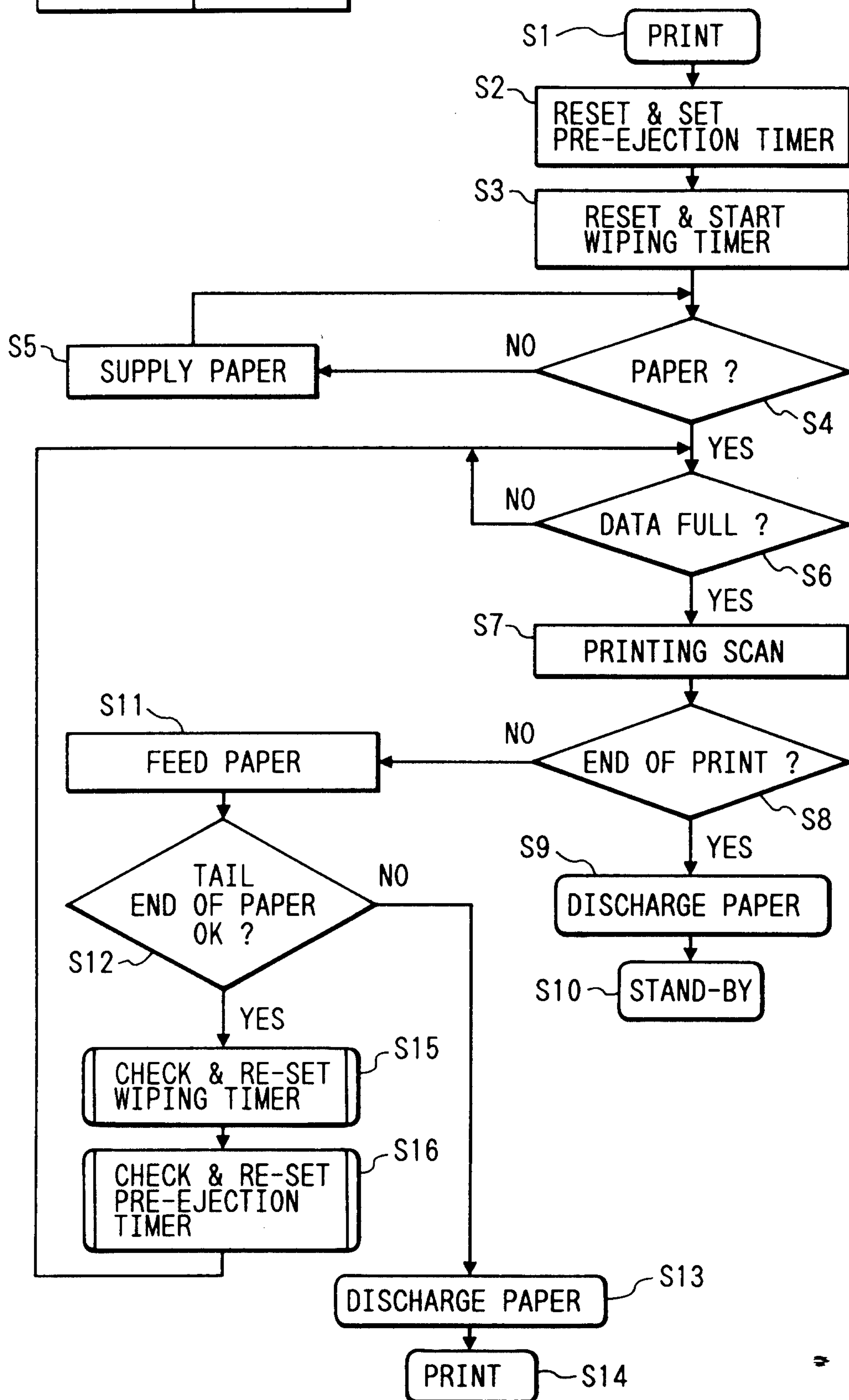


FIG. 15B

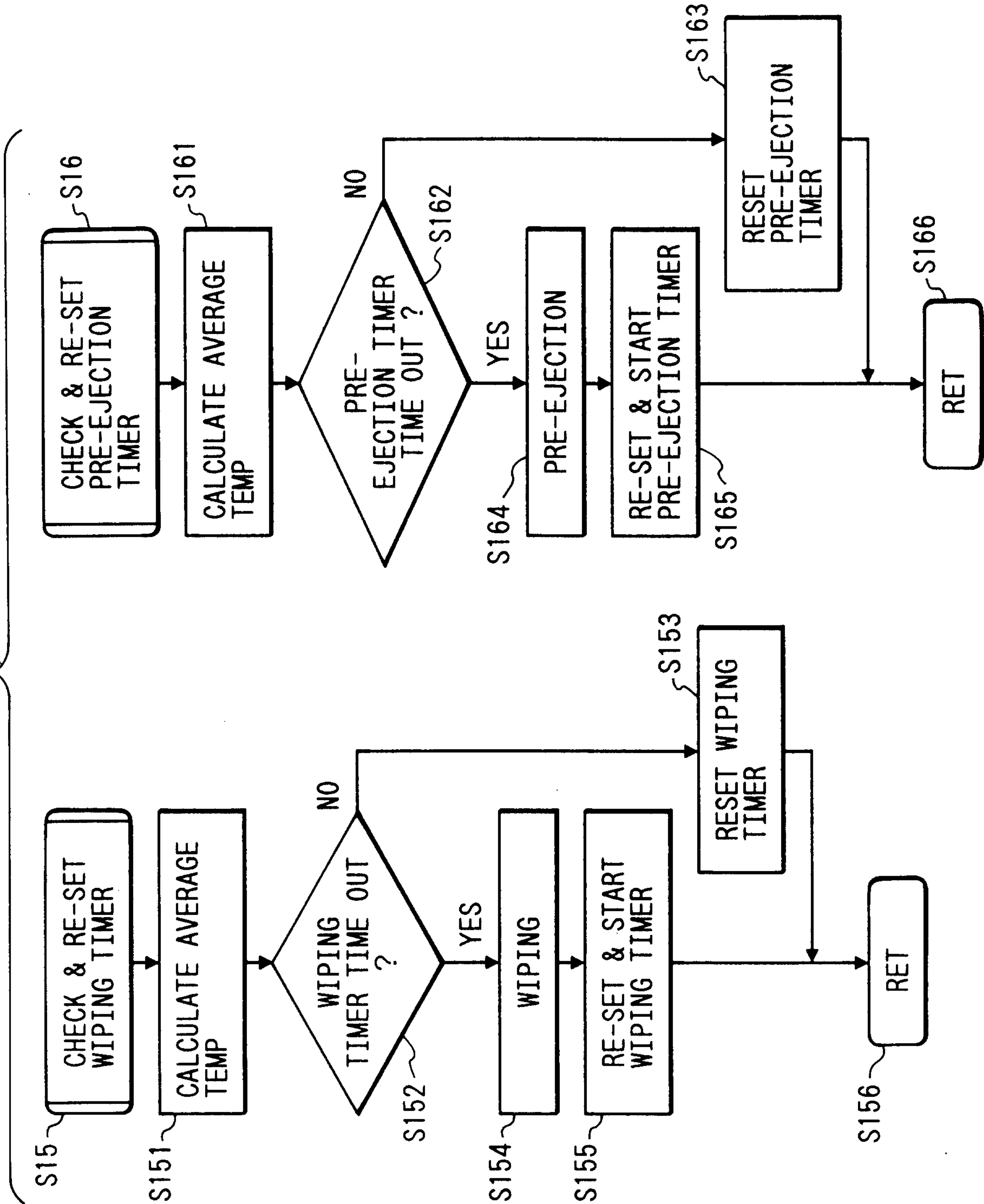


FIG. 16

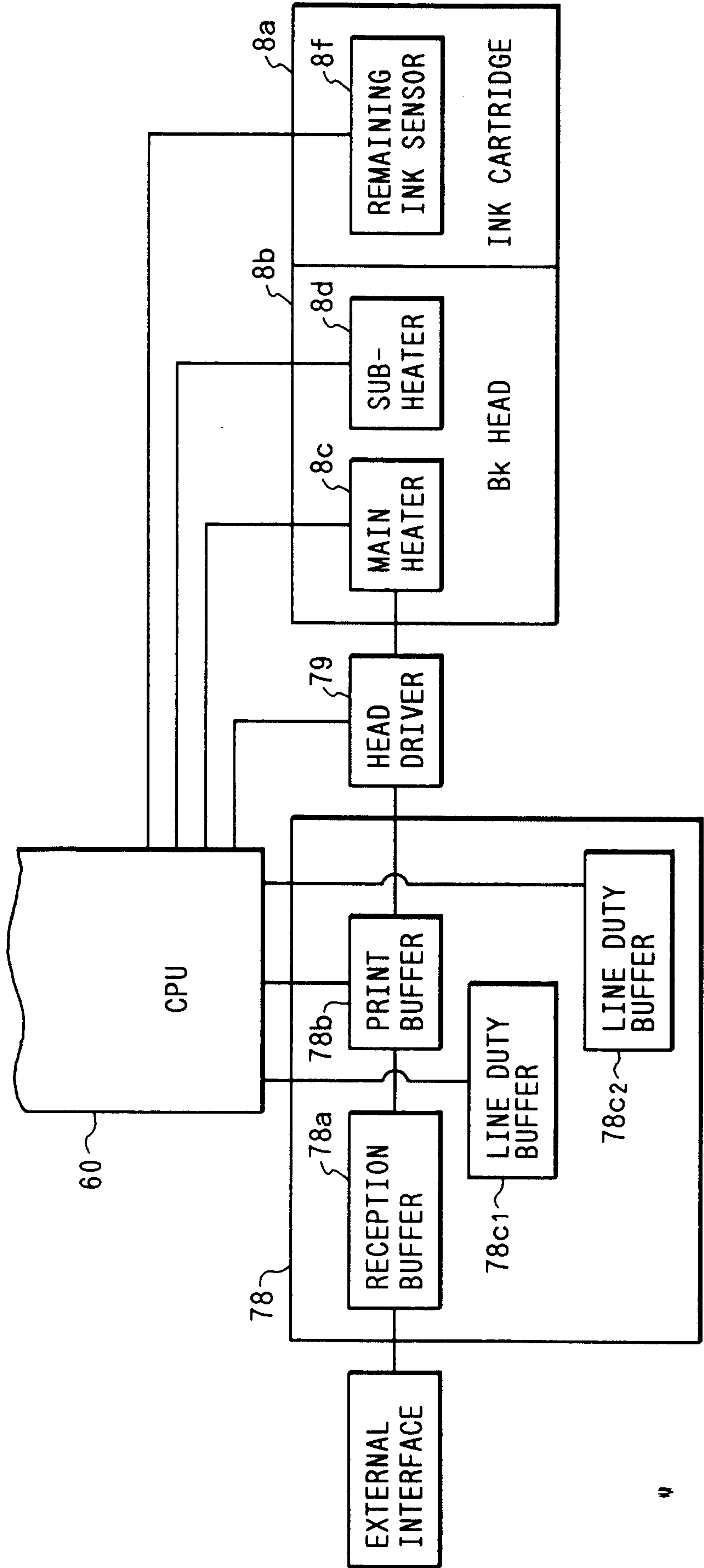


FIG. 17

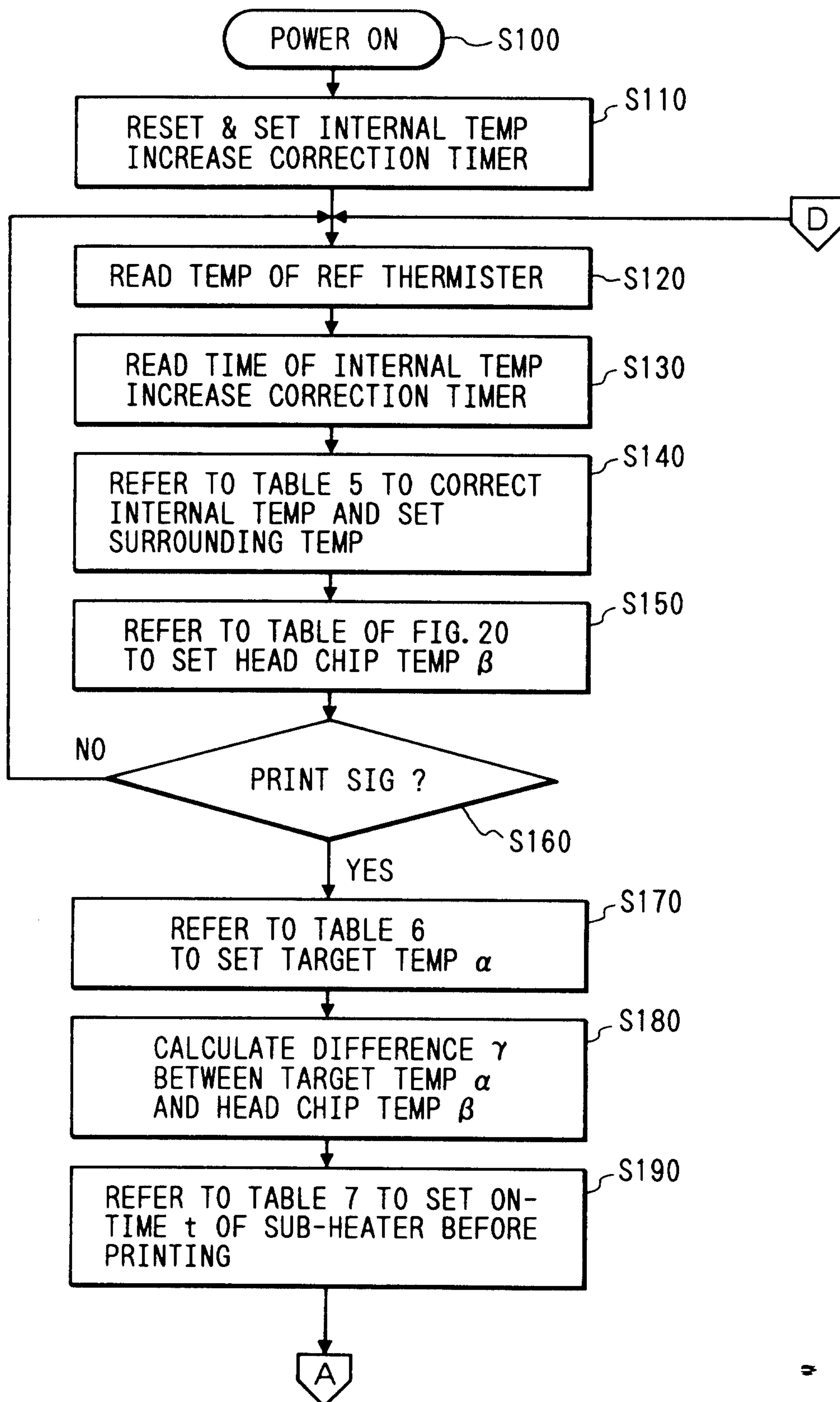


FIG. 18

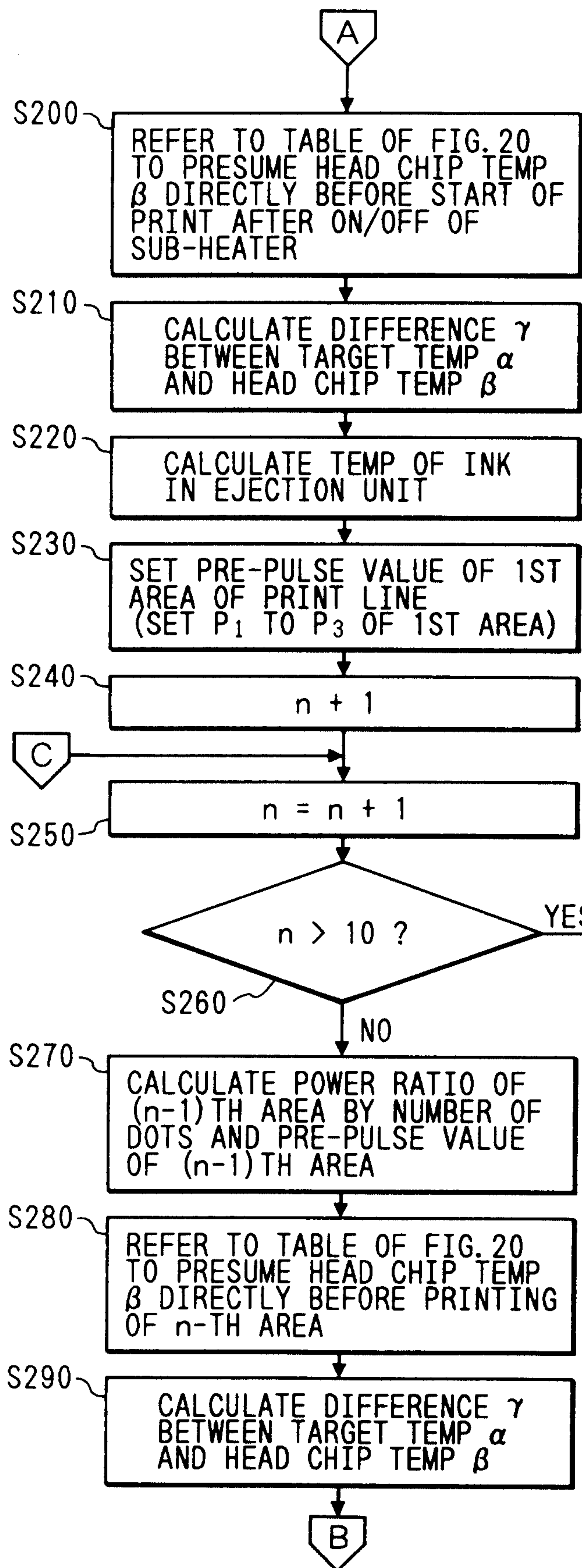


FIG. 19

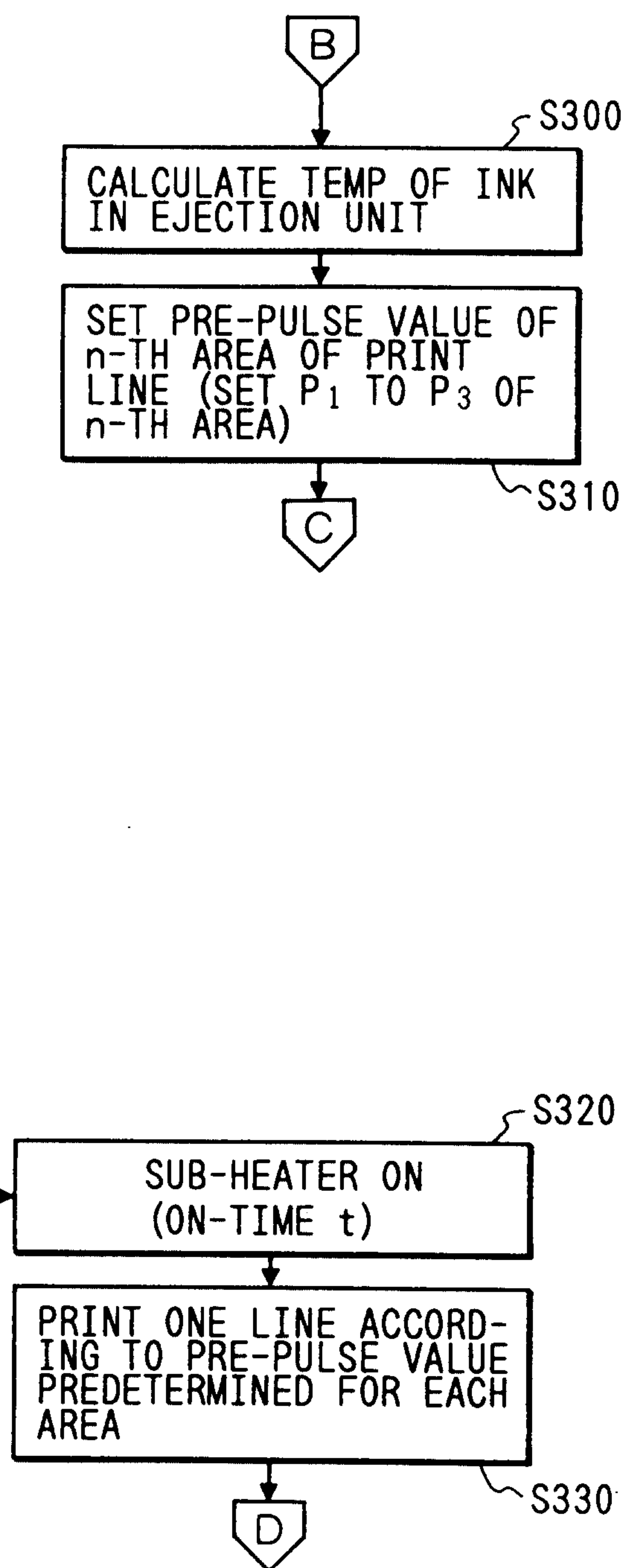


FIG. 20

HEAD TEMP ΔT															
	0~2.5	2.5~5	5~9	9~13	13~17	17~21	21~25	25~29	29~33	33~37	37~41	41~45	45~49		
POWER RATIO (APPLIED ENERGY TO HEAD/ UNIT TIME)	0~10	0	-0.005	-0.010	-0.018	-0.025	-0.030	-0.038	-0.050	-0.063	-0.075	-1.00			
	10~20	0.005	0	-0.004	-0.009	-0.015	-0.023	-0.030	-0.040	-0.052	-0.065	-0.40			
	20~30	0.008	0.004	0	-0.004	-0.008	-0.014	-0.022	-0.030	-0.041	-0.055	-0.10			
	30~40	0.015	0.008	0.004	0	-0.004	-0.008	-0.014	-0.022	-0.030	-0.045	-0.07			
	40~50	0.025	0.014	0.008	0.004	0	-0.004	-0.008	-0.014	-0.022	-0.035	-0.05			
	50~60	0.035	0.022	0.014	0.008	0.004	0	-0.004	-0.008	-0.014	-0.025	-0.04			
	60~70	0.045	0.030	0.022	0.014	0.008	0.004	0	-0.004	-0.008	-0.015	-0.03			
	70~80	0.055	0.041	0.030	0.022	0.014	0.008	0.004	0	-0.004	-0.008	-0.02			
	80~90	0.065	0.052	0.040	0.030	0.023	0.015	0.009	0.004	0	-0.005	-0.01			
	90~100.%	0.075	0.063	0.050	0.038	0.030	0.025	0.018	0.010	0.005	0	-0.007			
												-0.005			
φ	500 %	1.50	1.20	1.00	0.80	0.70	0.60	0.40	0.20	0.10	0.05	0.005			

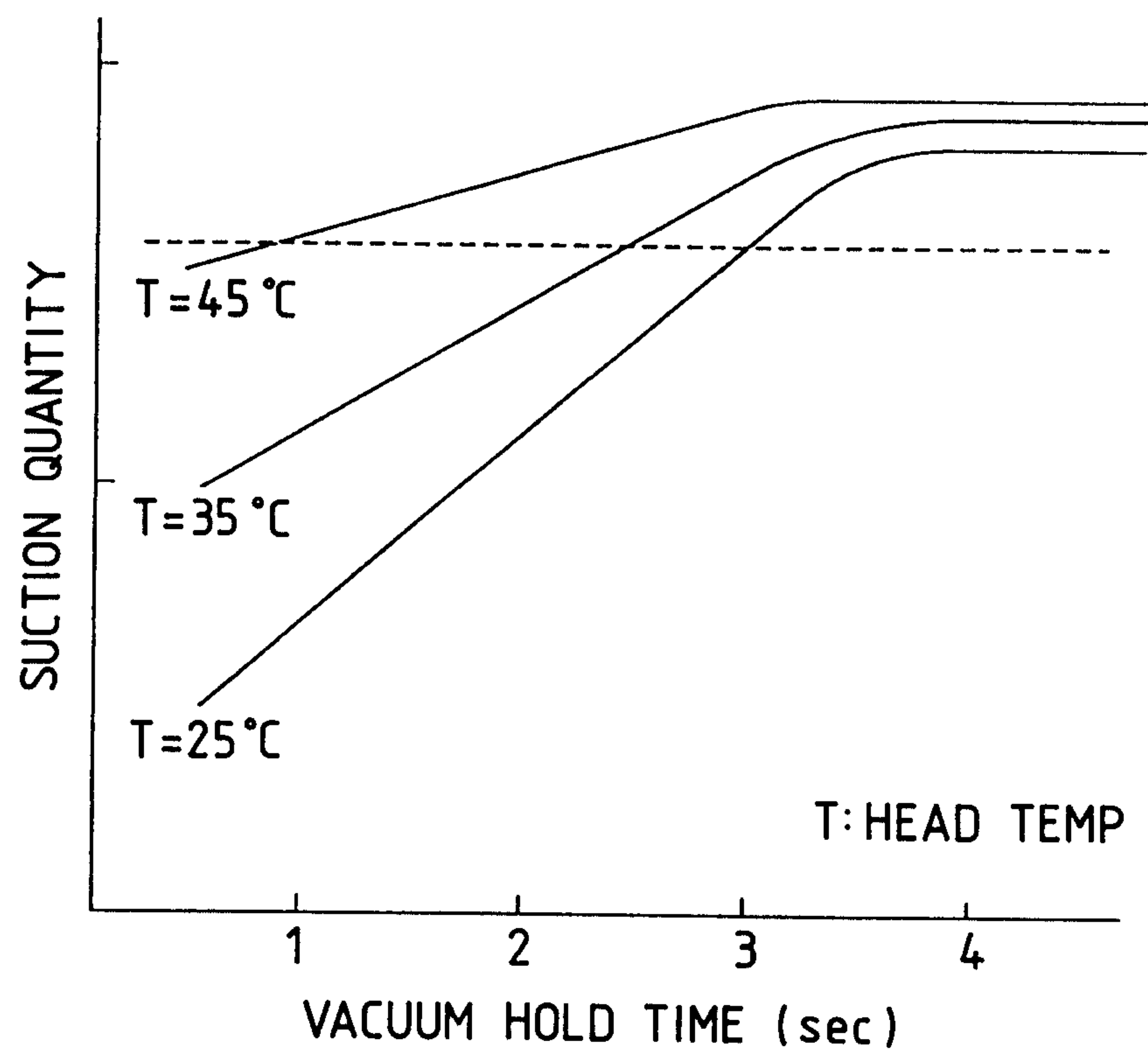
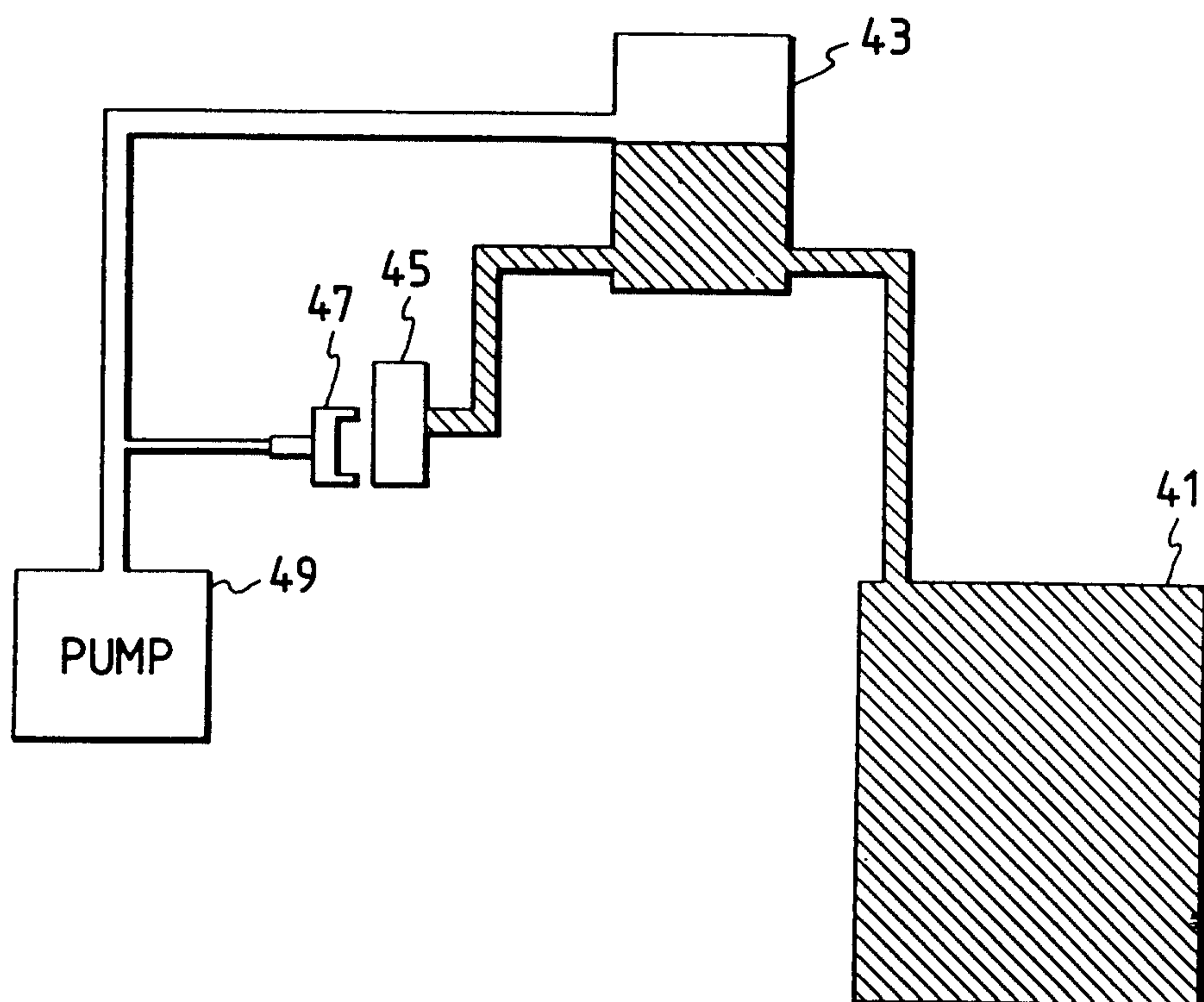
FIG. 21*FIG. 22*

FIG. 23

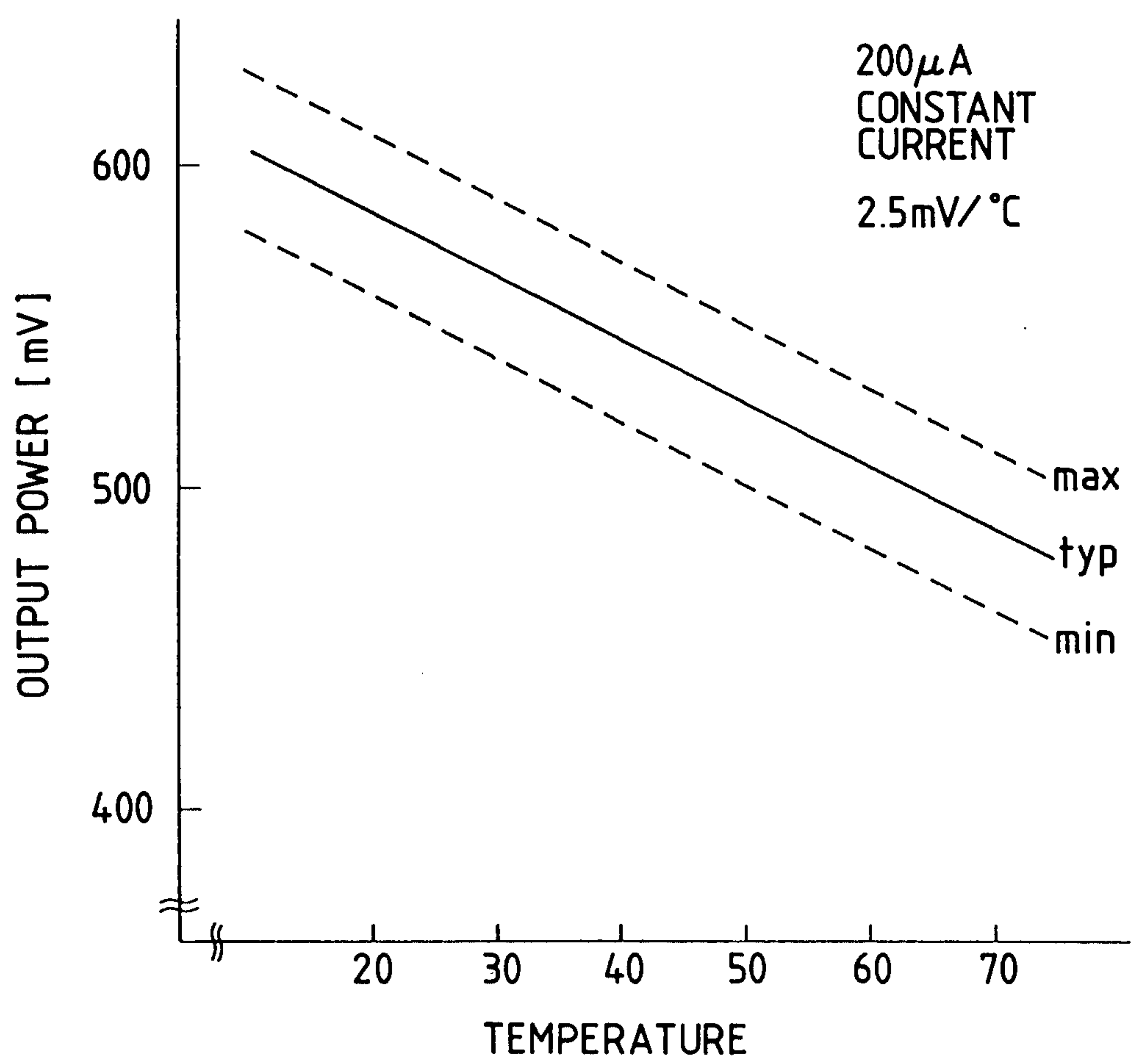


FIG. 24

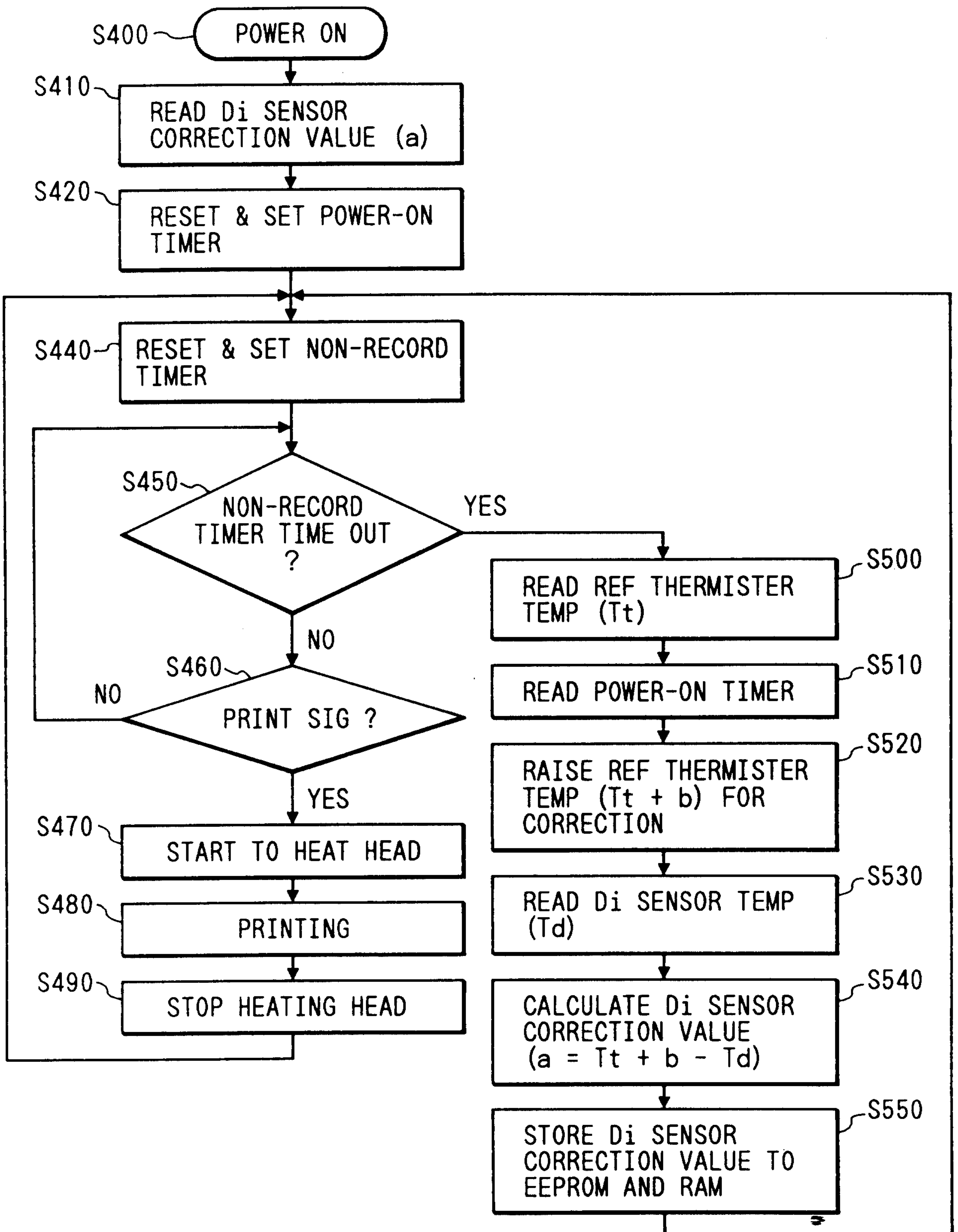


FIG. 25

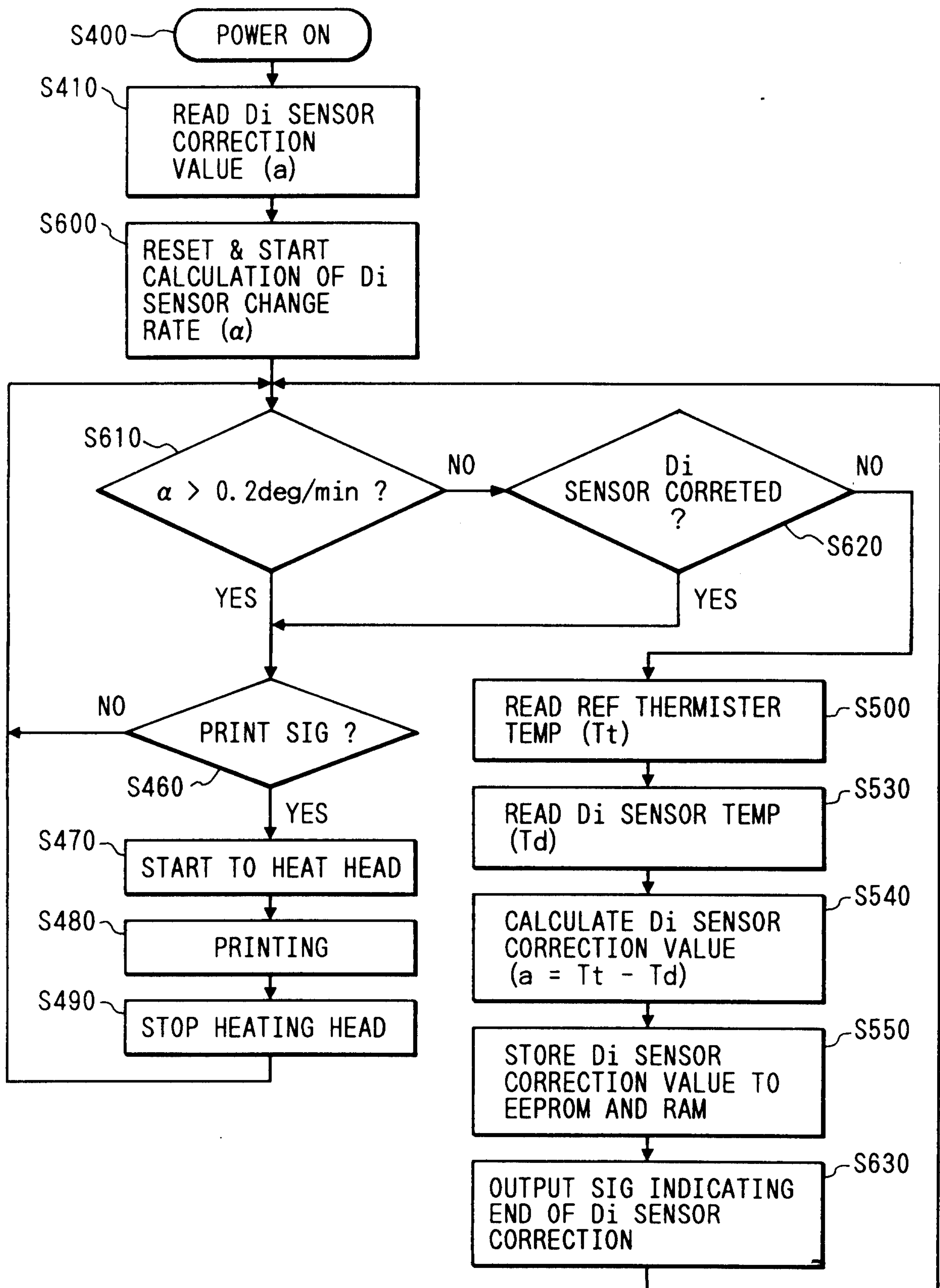


FIG. 26

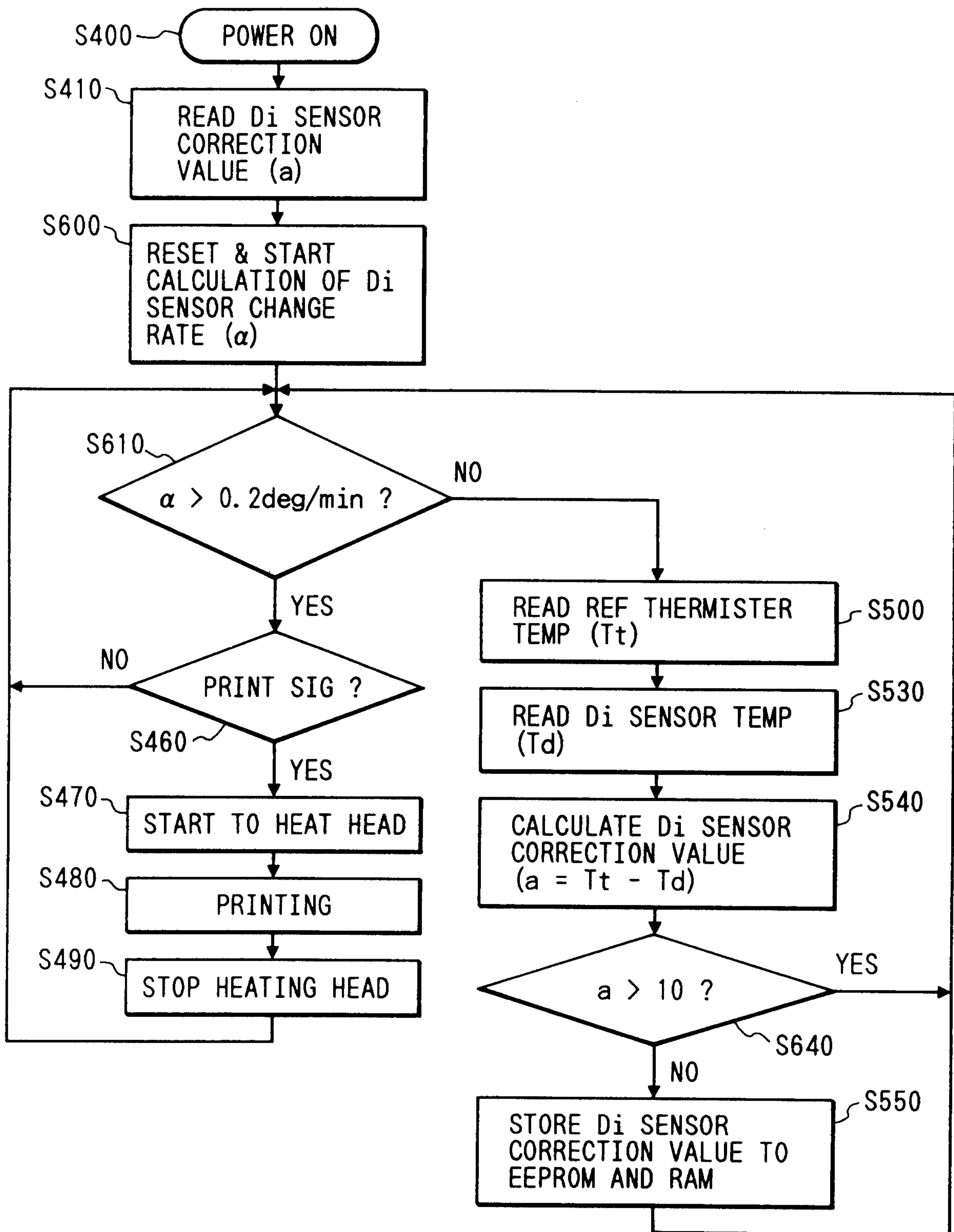


FIG. 27

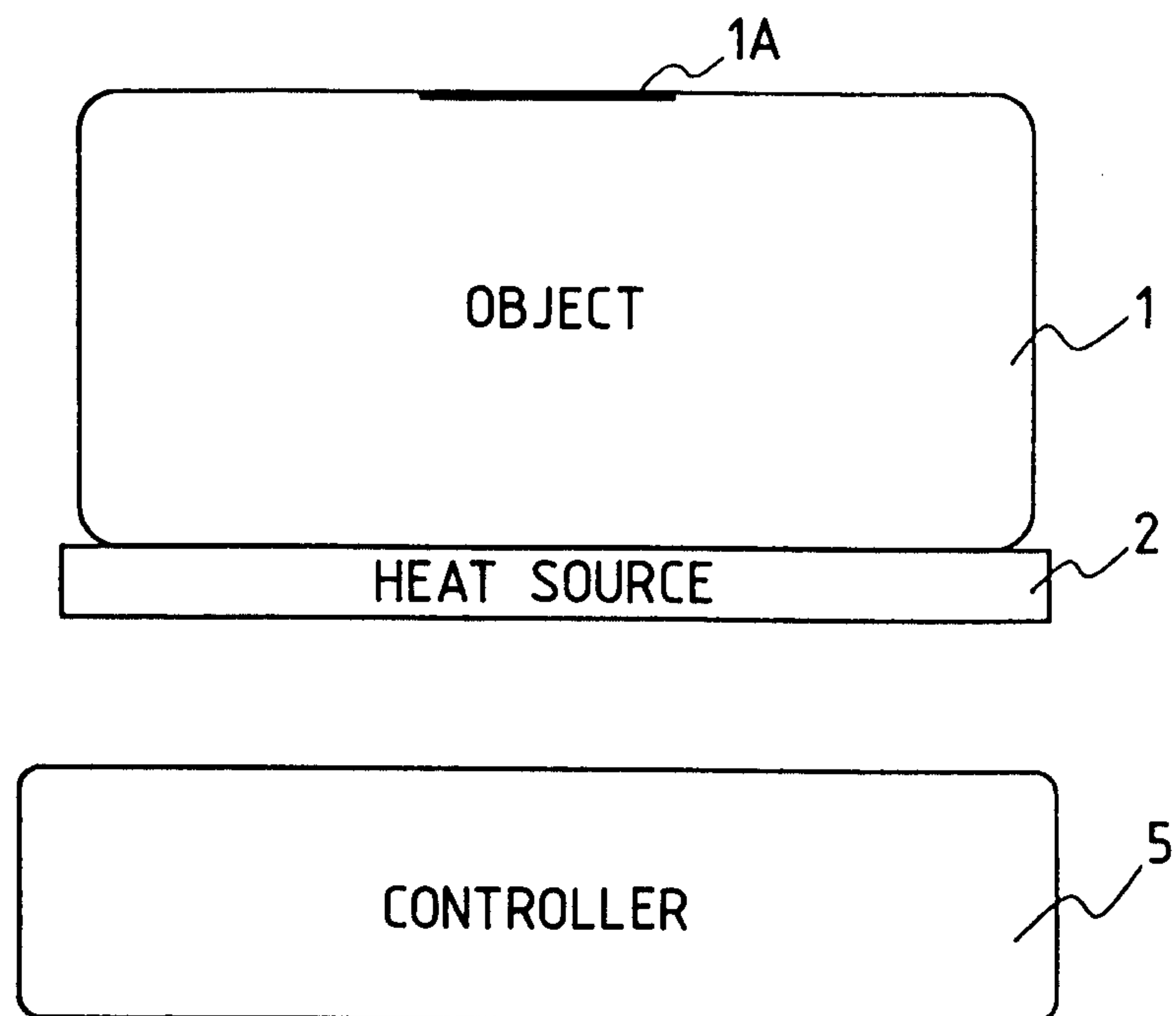


FIG. 28

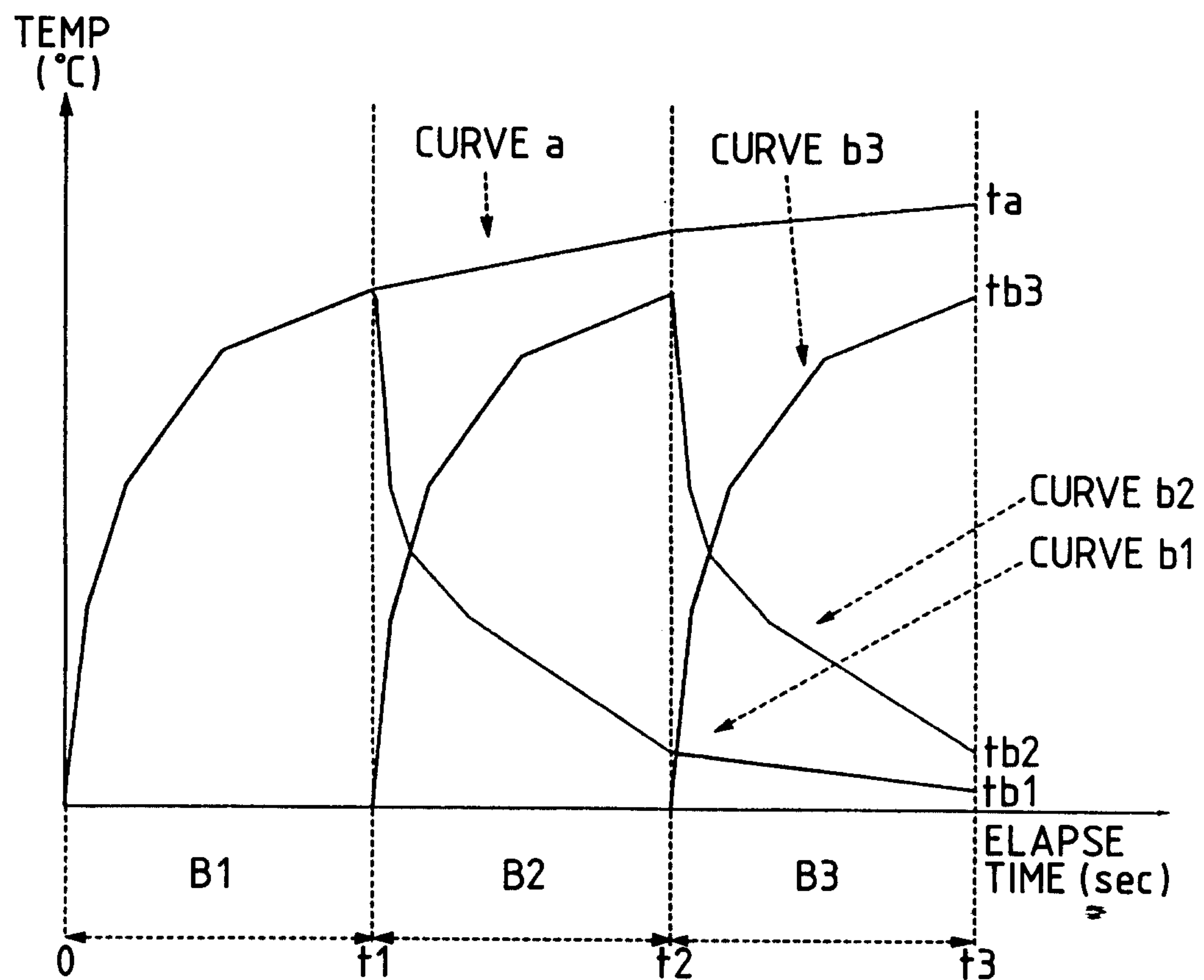


FIG. 29

DUTY (%) ELAPSE TIME	100	97.5	95.0	92.5	... 2.5% FOR EACH ... CONTINUED STAGE	0.0
0.1sec	13.7	13.4	13.1	12.8		0.0
0.2sec	4.0	3.5	3.0	2.6		0.0
0.3sec	2.5	2.3	2.1	2.0		0.0
0.4sec	1.8	1.8	1.8	1.7		0.0
0.5sec	1.5	1.5	1.5	1.5		0.0
0.6sec	1.2	1.2	1.2	1.2		0.0
0.7sec	0.9	0.8	0.8	0.8		0.0
0.8sec	0.7	0.7	0.7	0.6		0.0
0.9sec	0.6	0.6	0.6	0.5		0.0
1.0sec	0.5	0.5	0.5	0.4		0.0
1.1sec	0.4	0.4	0.4	0.4		0.0
1.2sec	0.3	0.3	0.3	0.3		0.0
1.3sec	0.2	0.2	0.2	0.2		0.0
1.4sec	0.1	0.1	0.1	0.1		0.0
1.5sec	0.1	0.1	0.1	0.1		0.0

FIG. 30

ELAPSE TIME		DUTY (%)	M1	M2	M3	M4	...	M15
(a)								
0.1sec		100	13.7	4.0	2.5	1.8	...	0.1
(b)								
0.2sec		100	4.0+13.7 =17.7	2.5+4.0 =6.5	1.8+2.5 =4.3	1.5+1.8 =3.3	...	0.0+0.1 =0.1
(c)								
0.3sec		95	6.5+13.1 =19.6	4.3+3.0 =7.3	3.3+2.1 =5.4	2.7+1.8 =4.5	...	0.0+0.1 =0.1
(d)								
0.4sec		0	7.3+0.0 =7.3	5.4+0.0 =5.4	4.5+0.0 =4.5	3.6+0.0 =3.6	...	0.0+0.0 =0.0

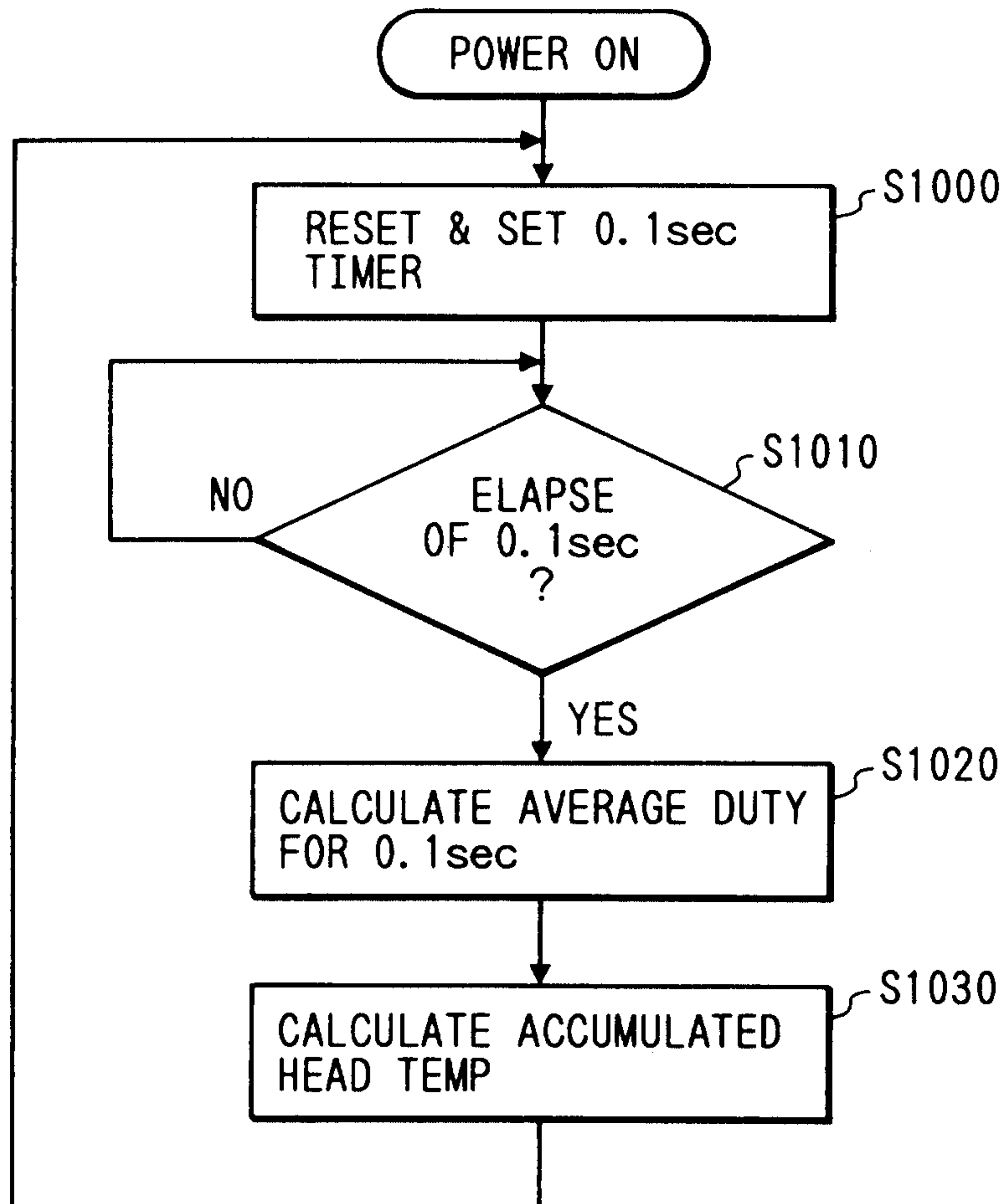
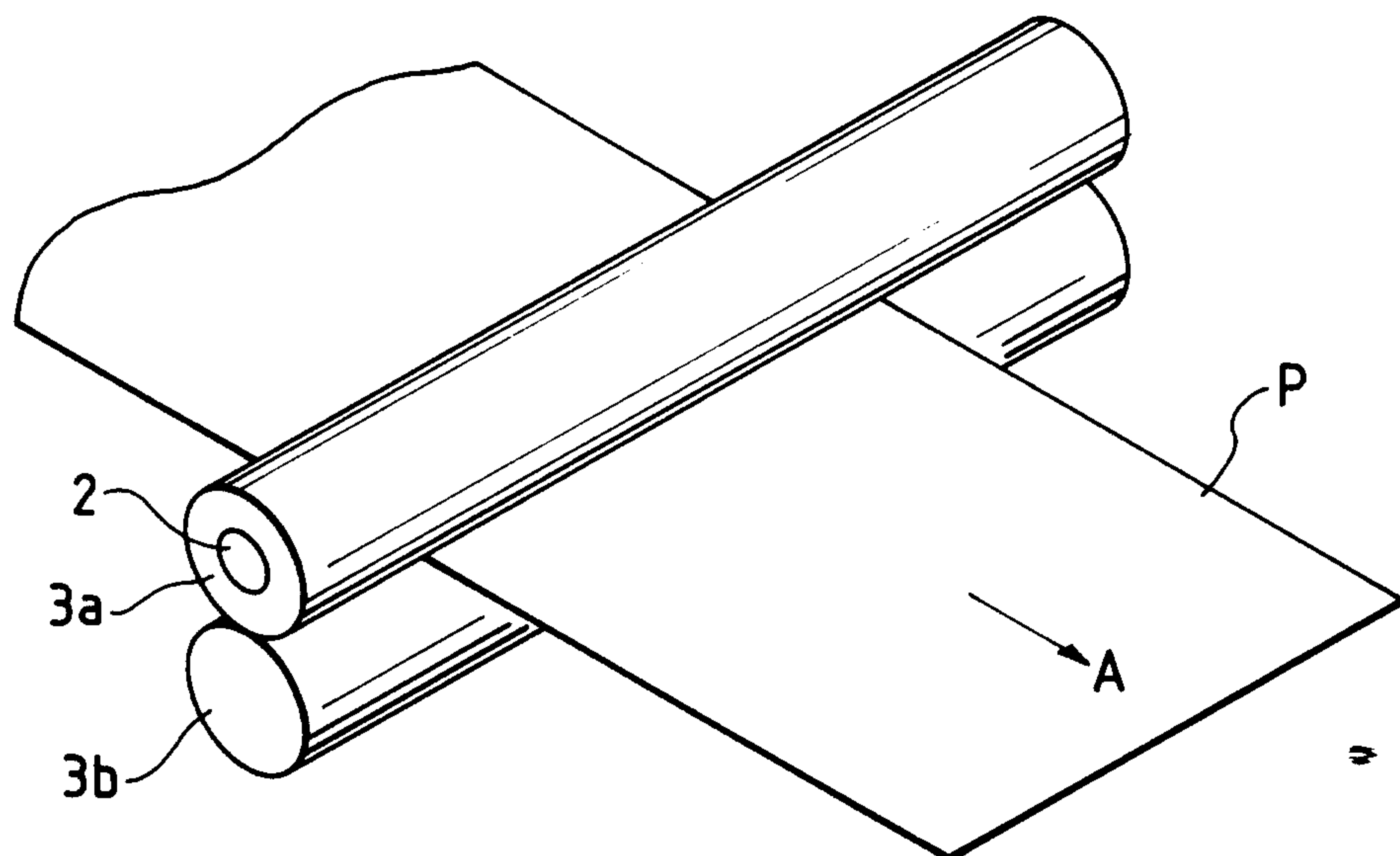
FIG. 31*FIG. 33*

FIG. 32

DUTY (%) ELAPSE TIME	100	97.5	95.0	92.5	DECREASE BY ...2.5% FOR EACH ... CONTINUED STAGE	0.0
0.1sec	12.4	12.2	12.0	11.7		0.0
0.2sec	6.3	6.0	5.7	5.5		0.0
0.3sec	3.4	3.0	2.8	2.5		0.0
0.4sec	2.2	1.8	1.5	1.4		0.0
0.5sec	1.8	1.5	1.3	1.1		0.0
⋮	⋮	⋮	⋮	⋮		⋮
⋮	⋮	⋮	⋮	⋮		⋮
⋮	⋮	⋮	⋮	⋮		⋮
59.5sec	0.2	0.2	0.1	0.1		0.0
59.6sec	0.1	0.1	0.1	0.1		0.0
59.7sec	0.1	0.1	0.1	0.1		0.0
59.8sec	0.1	0.1	0.1	0.1		0.0
59.9sec	0.1	0.1	0.1	0.0		0.0
60.0sec	0.1	0.0	0.0	0.0		0.0

FIG. 34

DUTY (%) ELAPSE TIME	100	95	90	85	DECREASE BY ... 5.0% FOR EACH ... CONTINUED STAGE	0.0
5sec	60.4	57.2	54.0	50.8		0.0
10sec	18.1	15.8	12.2	8.9		0.0
15sec	8.5	6.8	5.2	4.4		0.0
⋮	⋮	⋮	⋮	⋮		⋮
⋮	⋮	⋮	⋮	⋮		⋮
⋮	⋮	⋮	⋮	⋮		⋮
50sec	2.1	1.8	1.7	1.6		0.0
55sec	1.3	1.0	0.9	0.9		0.0
60sec	0.5	0.4	0.3	0.3		0.0

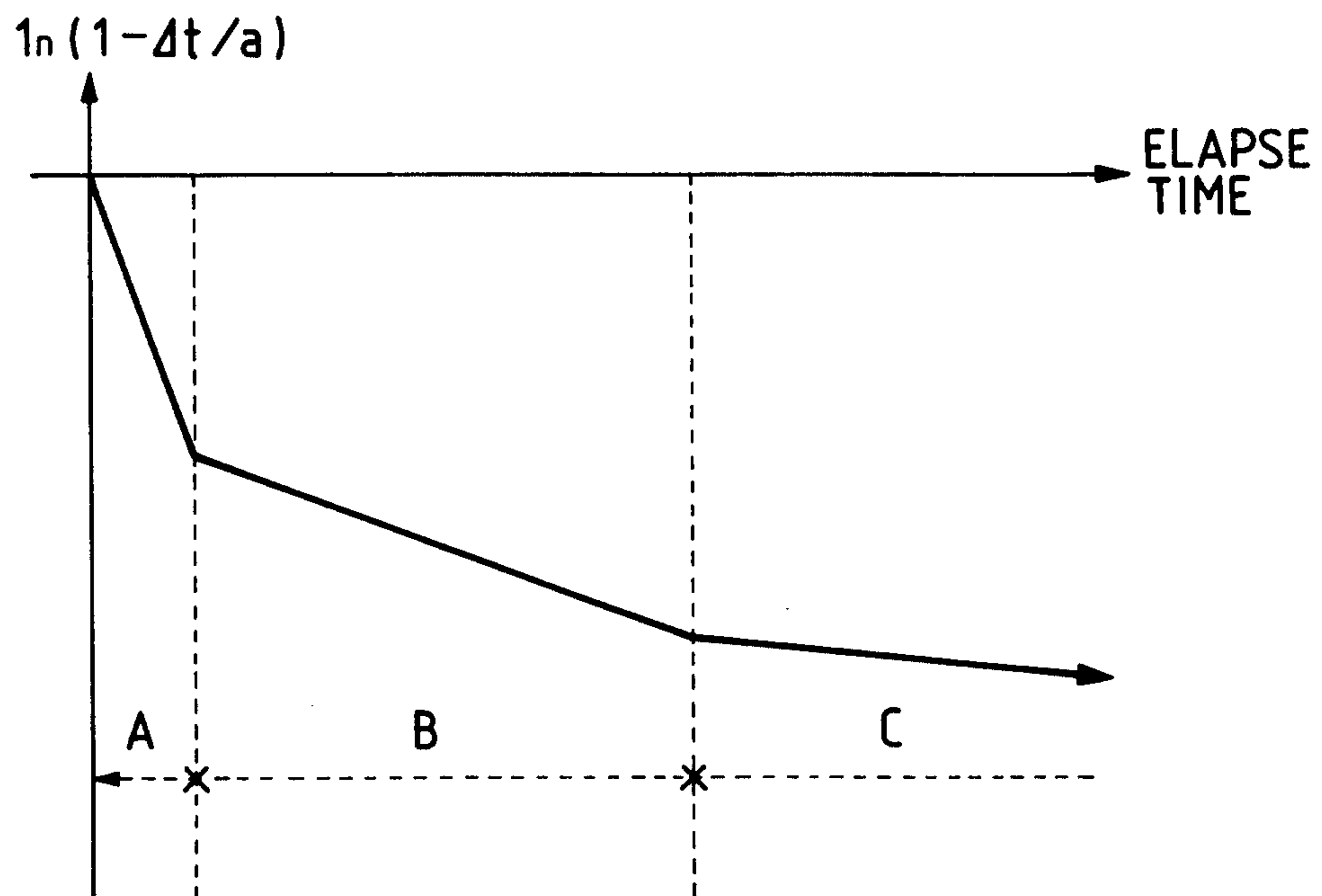
FIG. 35

T _R	T _T	T _R	T _T	T _R	T _T	T _R	T _T
0.0°C	35.5°C	17.5°C	26.0°C	35.0°C	15.0°C	52.5°C	15.0°C
0.5°C	35.5°C	18.0°C	26.0°C	35.5°C	15.0°C	53.0°C	15.0°C
1.0°C	35.5°C	18.5°C	25.5°C	36.0°C	15.0°C	53.5°C	15.0°C
1.5°C	35.5°C	19.0°C	25.5°C	36.5°C	15.0°C	54.0°C	15.0°C
2.0°C	35.5°C	19.5°C	25.0°C	37.0°C	15.0°C	54.5°C	15.0°C
2.5°C	35.5°C	20.0°C	24.5°C	37.5°C	15.0°C	55.0°C	15.0°C
3.0°C	35.5°C	20.5°C	24.5°C	38.0°C	15.0°C	55.5°C	15.0°C
3.5°C	35.5°C	21.0°C	24.0°C	38.5°C	15.0°C	56.0°C	15.0°C
4.0°C	35.5°C	21.5°C	24.0°C	39.0°C	15.0°C	56.5°C	15.0°C
4.5°C	35.5°C	22.0°C	23.5°C	39.5°C	15.0°C	57.0°C	15.0°C
5.0°C	35.5°C	22.5°C	23.5°C	40.0°C	15.0°C	57.5°C	15.0°C

11.5°C	30.5°C	29.0°C	19.0°C	46.5°C	15.0°C	64.0°C	15.0°C
12.0°C	30.0°C	29.5°C	18.5°C	47.0°C	15.0°C	64.5°C	15.0°C
12.5°C	29.5°C	30.0°C	18.0°C	47.5°C	15.0°C	65.0°C	15.0°C
13.0°C	29.0°C	30.5°C	18.0°C	48.0°C	15.0°C	65.5°C	15.0°C
13.5°C	28.5°C	31.0°C	17.5°C	48.5°C	15.0°C	66.0°C	15.0°C
14.0°C	28.5°C	31.5°C	17.0°C	49.0°C	15.0°C	66.5°C	15.0°C
14.5°C	28.0°C	32.0°C	17.0°C	49.5°C	15.0°C	67.0°C	15.0°C
15.0°C	27.5°C	32.5°C	16.5°C	50.0°C	15.0°C	67.5°C	15.0°C
15.5°C	27.0°C	33.0°C	16.0°C	50.5°C	15.0°C	68.0°C	15.0°C
16.0°C	27.0°C	33.5°C	16.0°C	51.0°C	15.0°C	68.5°C	15.0°C
16.5°C	26.5°C	34.0°C	15.5°C	51.5°C	15.0°C	69.0°C	15.0°C
17.0°C	26.5°C	34.5°C	15.0°C	52.0°C	15.0°C	69.5°C	15.0°C

T_R : SURROUNDING TEMPERATURE
T_T : TARGET TEMPERATURE

FIG. 36



a : EQUILIBRIUM TEMP
 Δt : INCREASED TEMP

FIG. 37

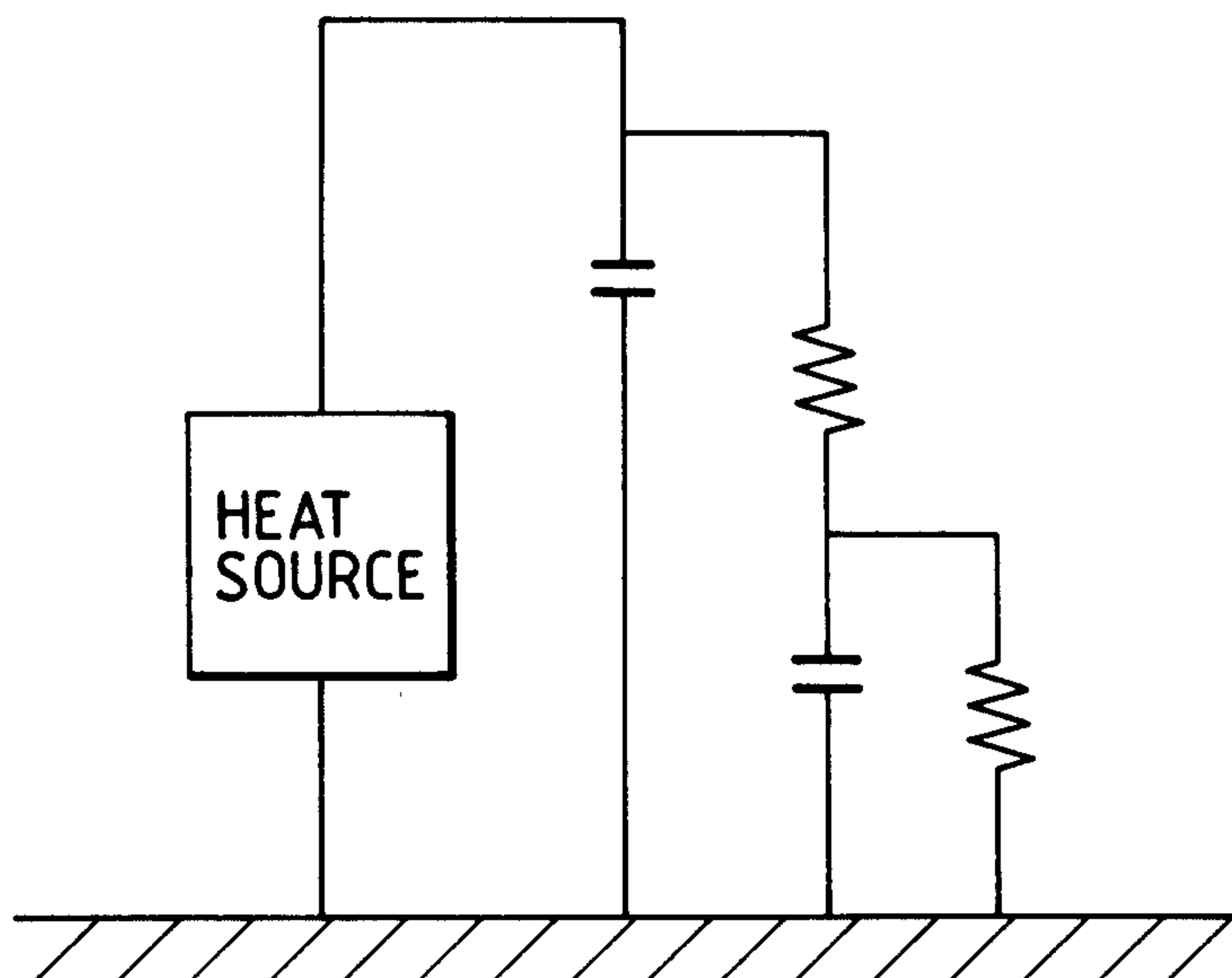


FIG. 38

HEAT SOURCE THERMAL TIME CONSTANT	EJECTION HEATER		SUB-HEATER	
	SHORT	LONG	SHORT	LONG
REQUIRED CALCULATION INTERVAL	0.05sec	1.00sec	0.05sec	1.00sec
DATA HOLD TIME	0.80sec	512sec	0.80sec	512sec

FIG. 39

[illegible]

FIG. 40

	0.0% ~	2.5% ~	5.0% ~	7.5% ~	10.0% ~	12.5% ~
1sec ~	0.00	0.15	0.27	0.39	0.52	0.62
3sec ~	0.00	0.08	0.16	0.24	0.32	0.37
5sec ~	0.00	0.07	0.09	0.11	0.13	0.17
7sec ~	0.00	0.12	0.14	0.16	0.18	0.20
9sec ~	0.00	0.06	0.11	0.15	0.20	0.22
11sec ~	0.00	0.05	0.07	0.09	0.11	0.13
21sec ~	0.00	0.04	0.05	0.06	0.07	0.08
41sec ~	0.00	0.03	0.04	0.05	0.06	0.06
61sec ~	0.00	0.02	0.03	0.04	0.05	0.05
81sec ~	0.00	0.01	0.02	0.03	0.04	0.04
101sec ~	0.00	0.02	0.02	0.02	0.03	0.03
151sec ~	0.00	0.01	0.01	0.01	0.02	0.02
301sec ~	0.00	0.01	0.01	0.01	0.01	0.01
512sec ~	0.00	0.00	0.00	0.00	0.00	0.00

87.5% ~	90.0% ~	92.5% ~	95.0% ~	97.5% ~
2.65	2.68	2.75	2.75	2.79
0.79	0.80	0.81	0.81	0.82
0.48	0.49	0.49	0.50	0.50
0.70	0.70	0.71	0.71	0.72
0.43	0.43	0.43	0.44	0.44
0.38	0.39	0.39	0.39	0.40
0.17	0.17	0.17	0.17	0.17
0.17	0.17	0.17	0.17	0.17
0.10	0.10	0.10	0.11	0.11
0.06	0.06	0.06	0.06	0.06
0.06	0.06	0.06	0.06	0.06
0.03	0.03	0.03	0.03	0.03
0.02	0.02	0.02	0.02	0.02
0.00	0.00	0.00	0.00	0.00

FIG. 41

	0.0% ~	20.0% ~	40.0% ~	60.0% ~	80.0% ~
0.05sec~	3.57	7.00	6.26	10.10	11.64
0.10sec~	2.25	4.20	4.10	6.24	7.16
0.15sec~	1.45	2.52	2.69	3.85	4.40
0.20sec~	0.93	1.51	1.76	2.38	2.71
0.25sec~	0.10	0.23	0.06	2.14	2.10
0.30sec~	0.15	0.24	0.24	0.55	0.68
0.35sec~	0.00	0.24	0.24	0.55	0.68
0.40sec~	0.00	0.24	0.24	0.55	0.68
0.45sec~	0.00	0.24	0.24	0.55	0.68
0.50sec~	0.00	0.24	0.24	0.55	0.68
0.55sec~	0.00	0.24	0.24	0.55	0.68
0.60sec~	0.00	0.24	0.24	0.55	0.68
0.65sec~	0.00	0.24	0.24	0.55	0.68
0.70sec~	0.00	0.24	0.24	0.55	0.68
0.75sec~	0.00	0.24	0.24	0.55	0.68
0.80sec~	0.00	0.24	0.24	0.55	0.68
0.85sec~	0.00	0.00	0.00	0.00	0.00

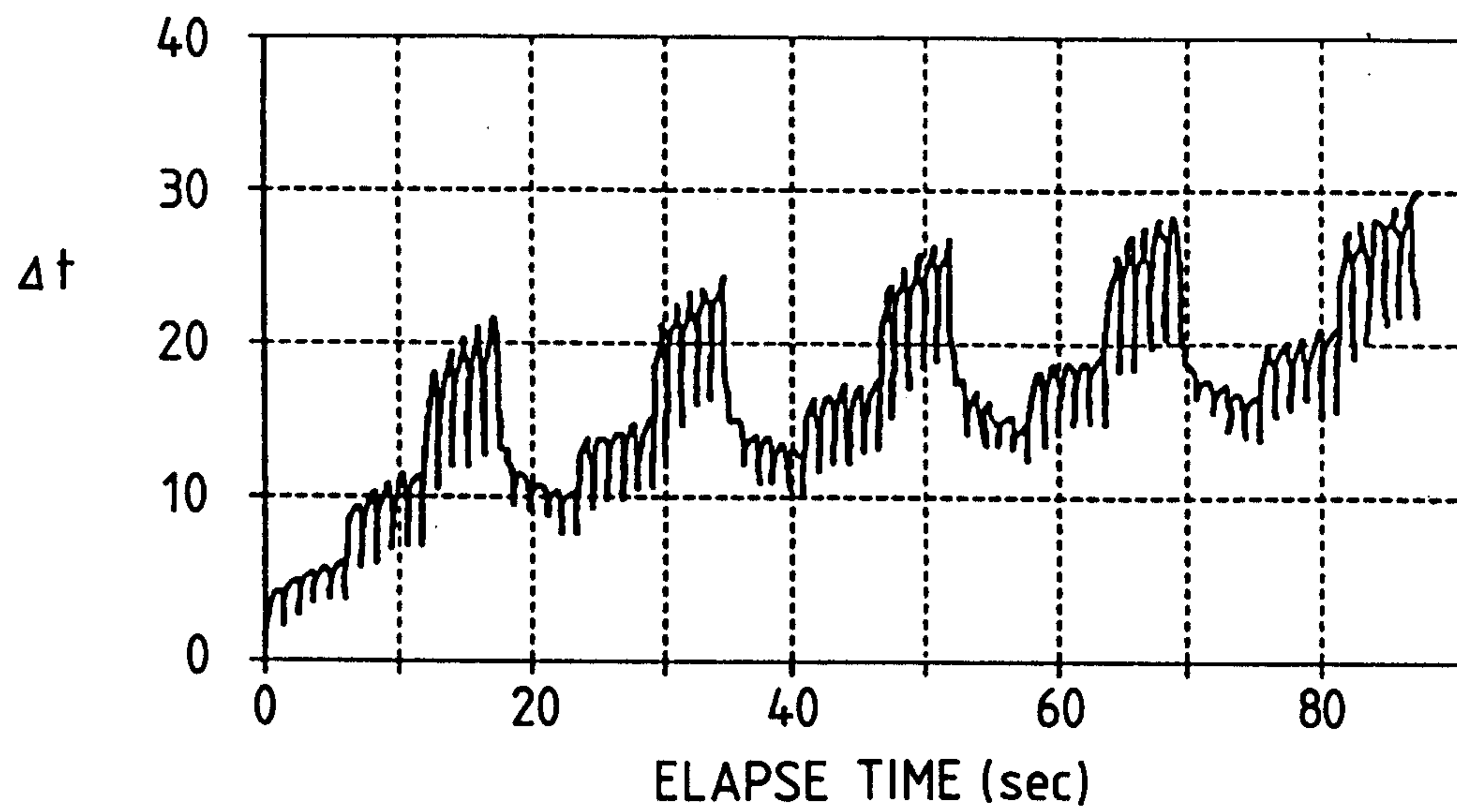
FIG. 42

	0.0% ~	2.5% ~	5.0% ~	7.5% ~	10.0% ~	12.5% ~	15.5% ~
1sec~	0.00	0.11	0.14	0.18	0.21	0.27	0.33
3sec~	0.00	0.14	0.13	0.12	0.12	0.16	0.20
5sec~	0.00	0.02	0.04	0.06	0.08	0.09	0.10
7sec~	0.00	0.03	0.07	0.10	0.13	0.14	0.15
9sec~	0.00	0.06	0.07	0.08	0.08	0.11	0.13
11sec~	0.00	0.04	0.04	0.05	0.06	0.07	0.08
21sec~	0.00	0.02	0.03	0.04	0.04	0.05	0.06
41sec~	0.00	0.02	0.02	0.03	0.04	0.04	0.04
61sec~	0.00	0.02	0.02	0.02	0.03	0.03	0.04
81sec~	0.00	0.01	0.01	0.02	0.02	0.02	0.03
101sec~	0.00	0.01	0.01	0.02	0.02	0.02	0.02
151sec~	0.00	0.01	0.01	0.01	0.01	0.01	0.01
301sec~	0.00	0.00	0.00	0.01	0.01	0.01	0.01
512sec~	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	87.5% ~	90.0% ~	92.5% ~	95.0% ~	97.5% ~
1sec~	1.74	1.83	1.91	2.00	2.08
3sec~	0.66	0.67	0.67	0.68	0.68
5sec~	0.40	0.41	0.41	0.41	0.42
7sec~	0.51	0.54	0.56	0.58	0.60
9sec~	0.35	0.36	0.36	0.36	0.37
11sec~	0.30	0.31	0.32	0.32	0.33
21sec~	0.14	0.14	0.14	0.14	0.14
41sec~	0.13	0.13	0.13	0.14	0.14
61sec~	0.08	0.08	0.09	0.09	0.09
81sec~	0.06	0.05	0.05	0.05	0.05
101sec~	0.04	0.04	0.05	0.05	0.05
151sec~	0.02	0.02	0.02	0.02	0.02
301sec~	0.01	0.01	0.01	0.01	0.01
512sec~	0.00	0.00	0.00	0.00	0.00

FIG. 43A

SIMULATION RESULT

*FIG. 43B*

MEASUREMENT RESULT

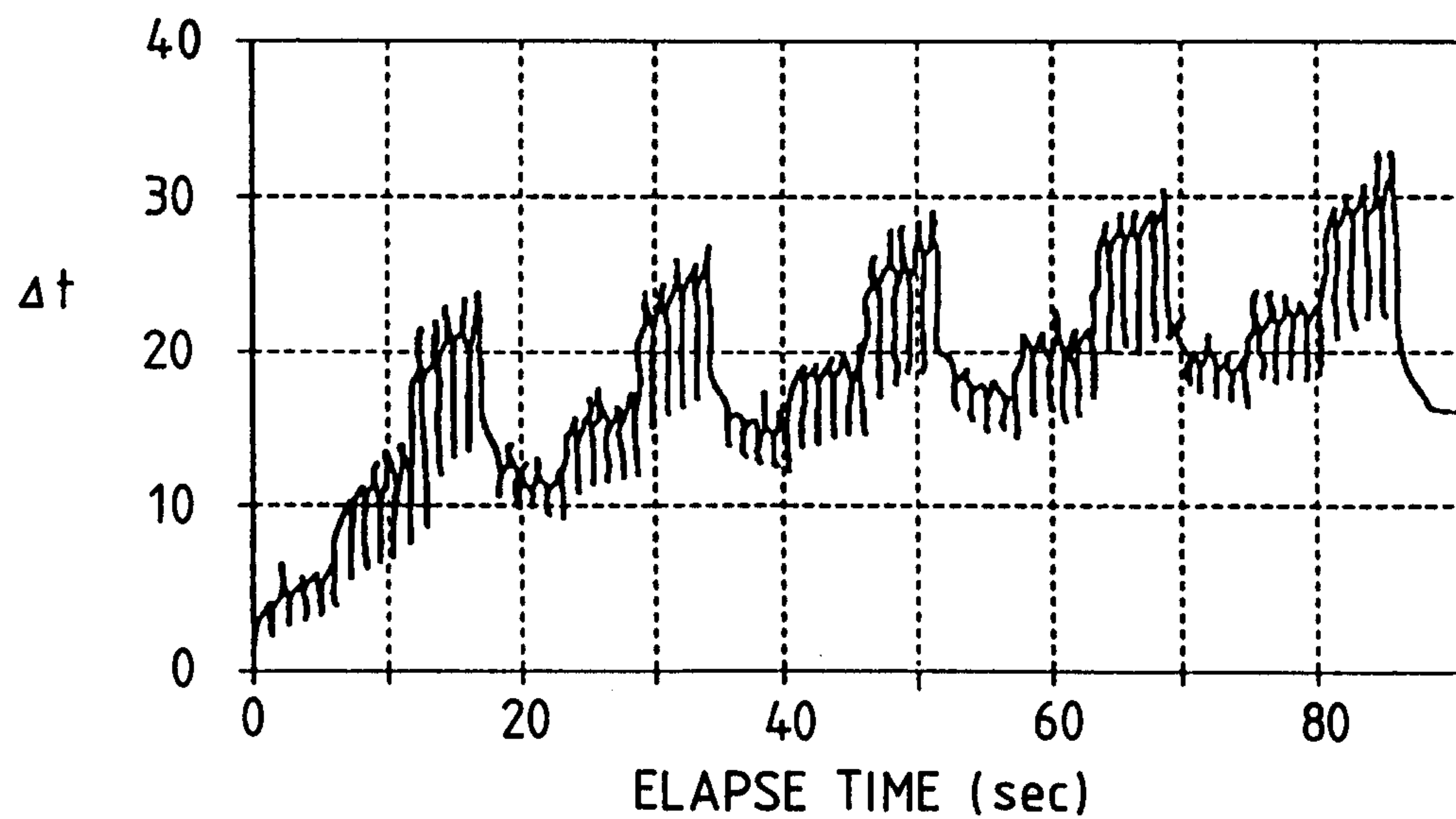


FIG. 44

TEMP DIFFERENCE	SET-UP	PRE-HEAT	INTERVAL	MAIN	WEIGHT
-52.5°C~	0.905μsec	0.000μsec	0.000μsec	4.525μsec	60%
-49.5°C~	0.905μsec	0.000μsec	0.000μsec	4.525μsec	60%
-46.5°C~	0.905μsec	0.000μsec	0.000μsec	4.525μsec	60%
-43.5°C~	0.905μsec	0.000μsec	0.000μsec	4.525μsec	60%
-40.5°C~	0.905μsec	0.000μsec	0.000μsec	4.525μsec	60%
-37.5°C~	0.905μsec	0.000μsec	0.000μsec	4.525μsec	60%
-34.5°C~	0.905μsec	0.000μsec	0.000μsec	4.525μsec	60%
-31.5°C~	0.905μsec	0.000μsec	0.000μsec	4.525μsec	60%
-28.5°C~	0.905μsec	0.000μsec	0.000μsec	4.887μsec	64%
-25.5°C~	0.905μsec	0.000μsec	0.000μsec	5.068μsec	68%
-22.5°C~	0.905μsec	0.000μsec	0.000μsec	5.249μsec	72%
-19.5°C~	0.905μsec	0.000μsec	0.000μsec	5.611μsec	76%
-16.5°C~	0.905μsec	0.000μsec	0.000μsec	5.972μsec	80%
-13.5°C~	0.905μsec	0.000μsec	0.000μsec	5.973μsec	84%
-10.5°C~	0.905μsec	0.000μsec	0.000μsec	6.335μsec	88%
-7.5°C~	0.905μsec	0.000μsec	0.000μsec	6.516μsec	92%
-4.5°C~	0.905μsec	0.000μsec	0.000μsec	6.697μsec	96%
-1.5°C~	0.905μsec	0.000μsec	0.000μsec	7.059μsec	100%
1.5°C~	0.905μsec	1.991μsec	0.543μsec	5.068μsec	100%
4.5°C~	0.905μsec	1.991μsec	0.905μsec	5.068μsec	100%
7.5°C~	0.905μsec	1.991μsec	1.448μsec	5.068μsec	100%
10.5°C~	0.905μsec	1.991μsec	1.991μsec	5.068μsec	100%
13.5°C~	0.905μsec	1.991μsec	1.991μsec	5.068μsec	100%
16.5°C~	0.905μsec	1.991μsec	1.991μsec	5.068μsec	100%
19.5°C~	0.905μsec	1.991μsec	1.991μsec	5.068μsec	100%
22.5°C~	0.905μsec	1.991μsec	1.991μsec	5.068μsec	100%
25.5°C~	0.905μsec	1.991μsec	1.991μsec	5.068μsec	100%
28.5°C~	0.905μsec	1.991μsec	1.991μsec	5.068μsec	100%
31.5°C~	0.905μsec	1.991μsec	1.991μsec	5.068μsec	100%
34.5°C~	0.905μsec	1.991μsec	1.991μsec	5.068μsec	100%
37.5°C~	0.905μsec	1.991μsec	1.991μsec	5.068μsec	100%

FIG. 45

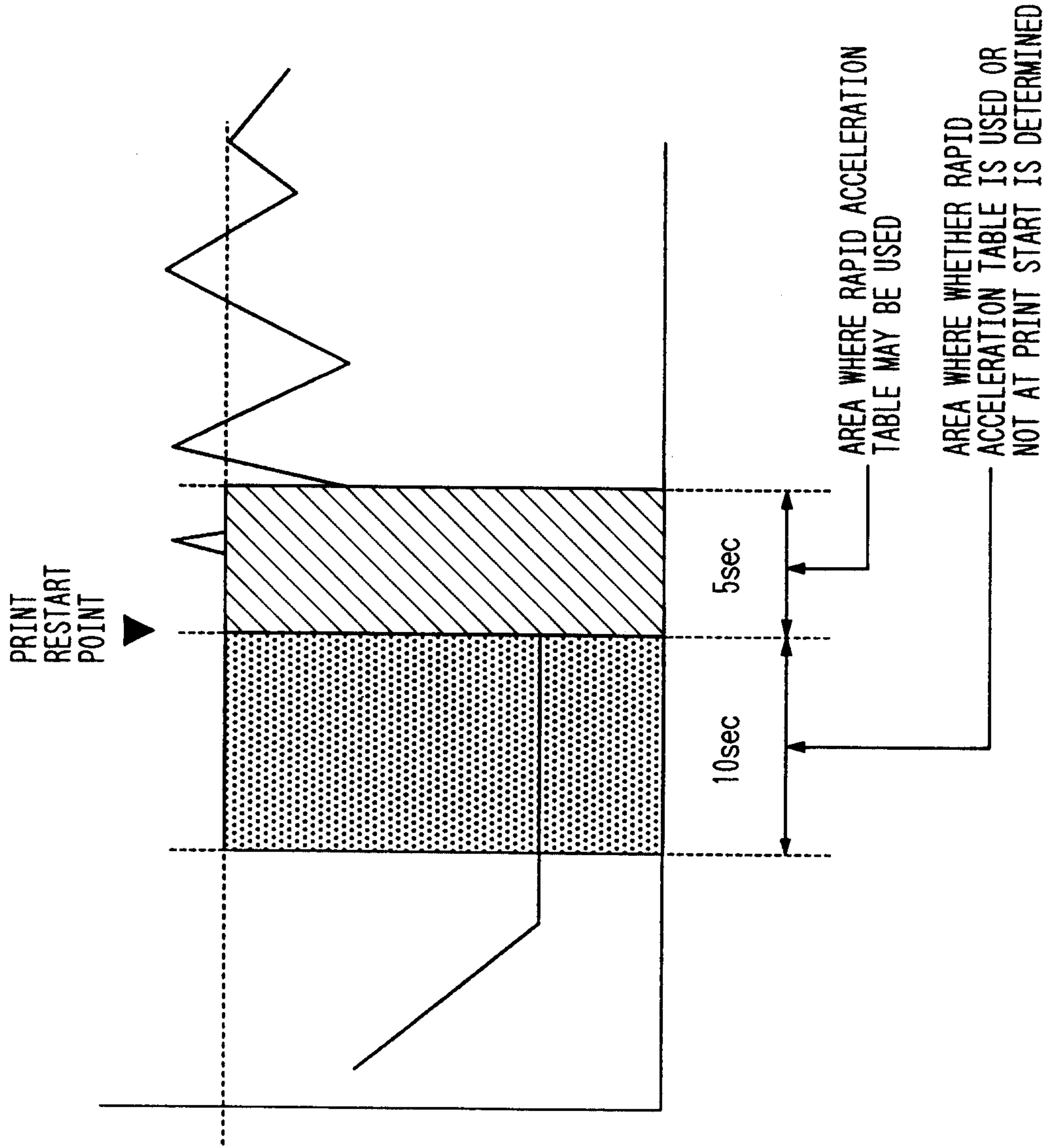


FIG. 46

TEMP DIFFERENCE	LONG	SHORT
0°C	0.0sec	0msec
1°C	0.0sec	0msec
2°C	0.0sec	0msec
3°C	0.0sec	0msec
4°C	0.0sec	0msec
5°C	0.0sec	0msec
6°C	0.0sec	0msec
7°C	0.0sec	0msec
8°C	0.0sec	0msec
9°C	0.0sec	0msec
10°C	0.0sec	0msec
11°C	0.0sec	0msec
12°C	0.0sec	0msec
13°C	0.0sec	0msec
14°C	0.1sec	10msec
15°C	0.2sec	20msec
16°C	0.4sec	40msec
17°C	0.5sec	50msec
18°C	0.6sec	60msec
19°C	0.7sec	70msec
20°C	0.8sec	80msec
21°C	0.9sec	90msec
22°C	1.1sec	110msec
23°C	1.2sec	120msec
24°C	1.3sec	130msec
25°C	1.4sec	140msec
26°C	1.5sec	150msec
27°C	1.7sec	160msec
28°C	1.8sec	180msec
29°C	1.9sec	190msec
30°C	2.0sec	200msec
31°C	2.0sec	200msec
32°C	2.0sec	200msec
33°C	2.0sec	200msec
34°C	2.0sec	200msec
35°C	2.0sec	200msec
36°C	2.0sec	200msec
37°C	2.0sec	200msec
38°C	2.0sec	200msec
39°C	2.0sec	200msec

FIG. 47

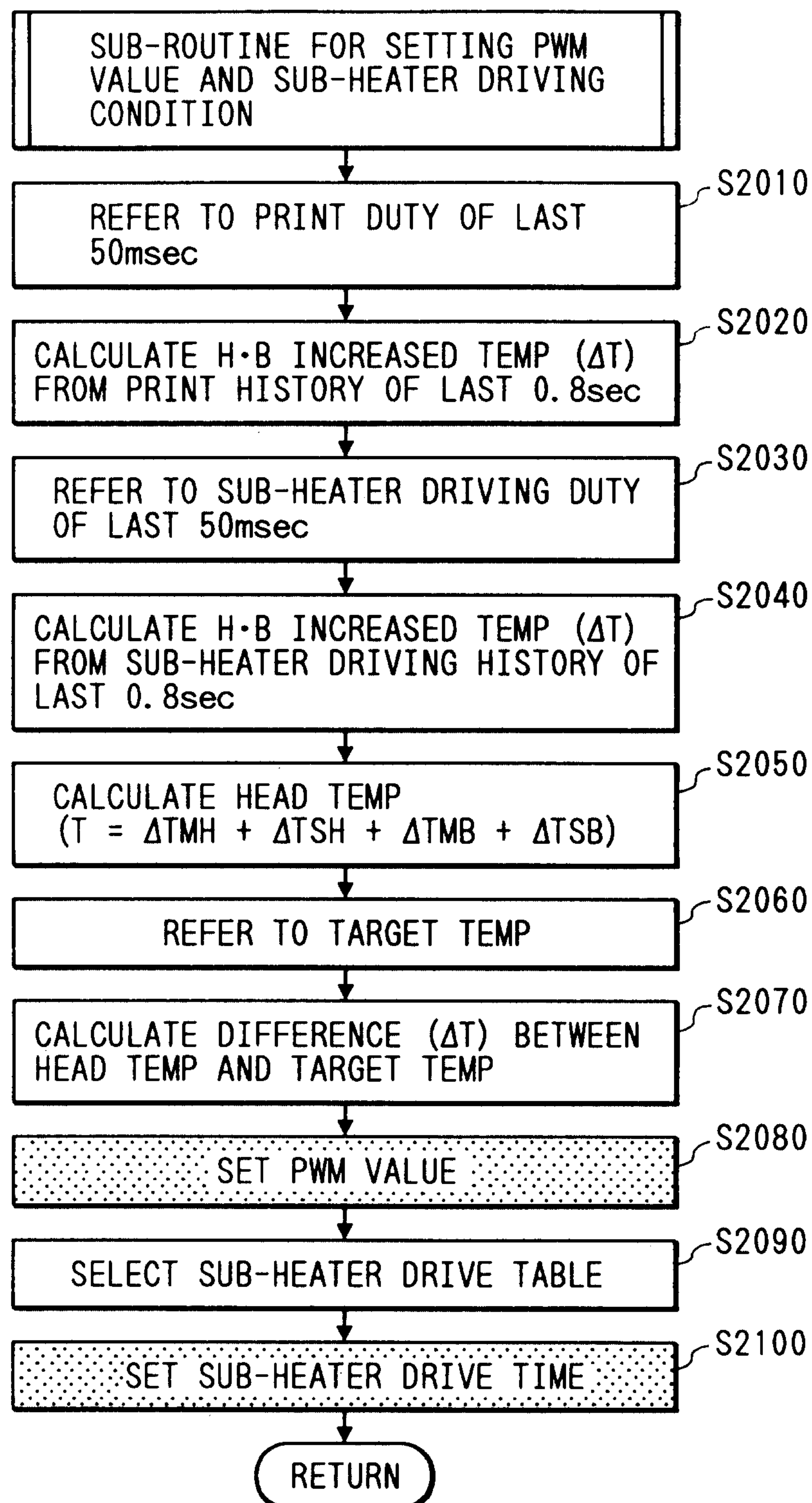


FIG. 48

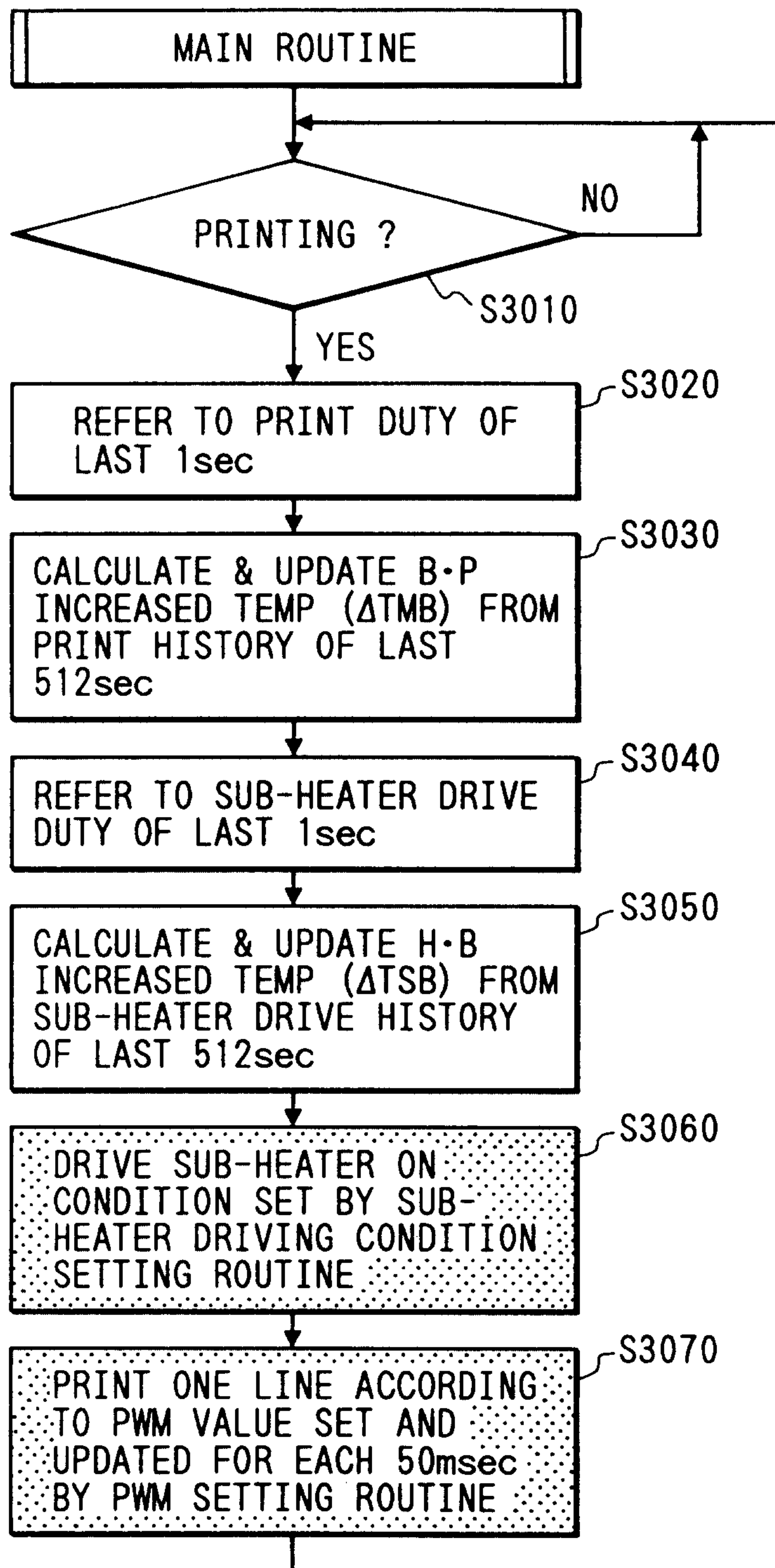


FIG. 49

PRESUMED HEAD TEMP (°C)	PULSE WIDTH (μ sec)
20 ~ 30	7.0
30 ~ 40	6.5
40 ~ 50	6.0
50 ~	5.5

FIG. 50

PRESUMED HEAD TEMP (°C)	1 ~ 16 NOZZLES	17 ~ 48 NOZZLES	49 ~ 64 NOZZLES
20 ~ 30	10	8	10
30 ~ 40	10	7	10
40 ~ 50	10	6	10
50 ~	10	5	10

FIG. 51

PRESUMED HEAD TEMP (°C)	Y, M, C	Bk
20 ~ 30	16	24
30 ~ 40	14	21
40 ~ 50	12	18
50 ~	10	15

FIG. 52

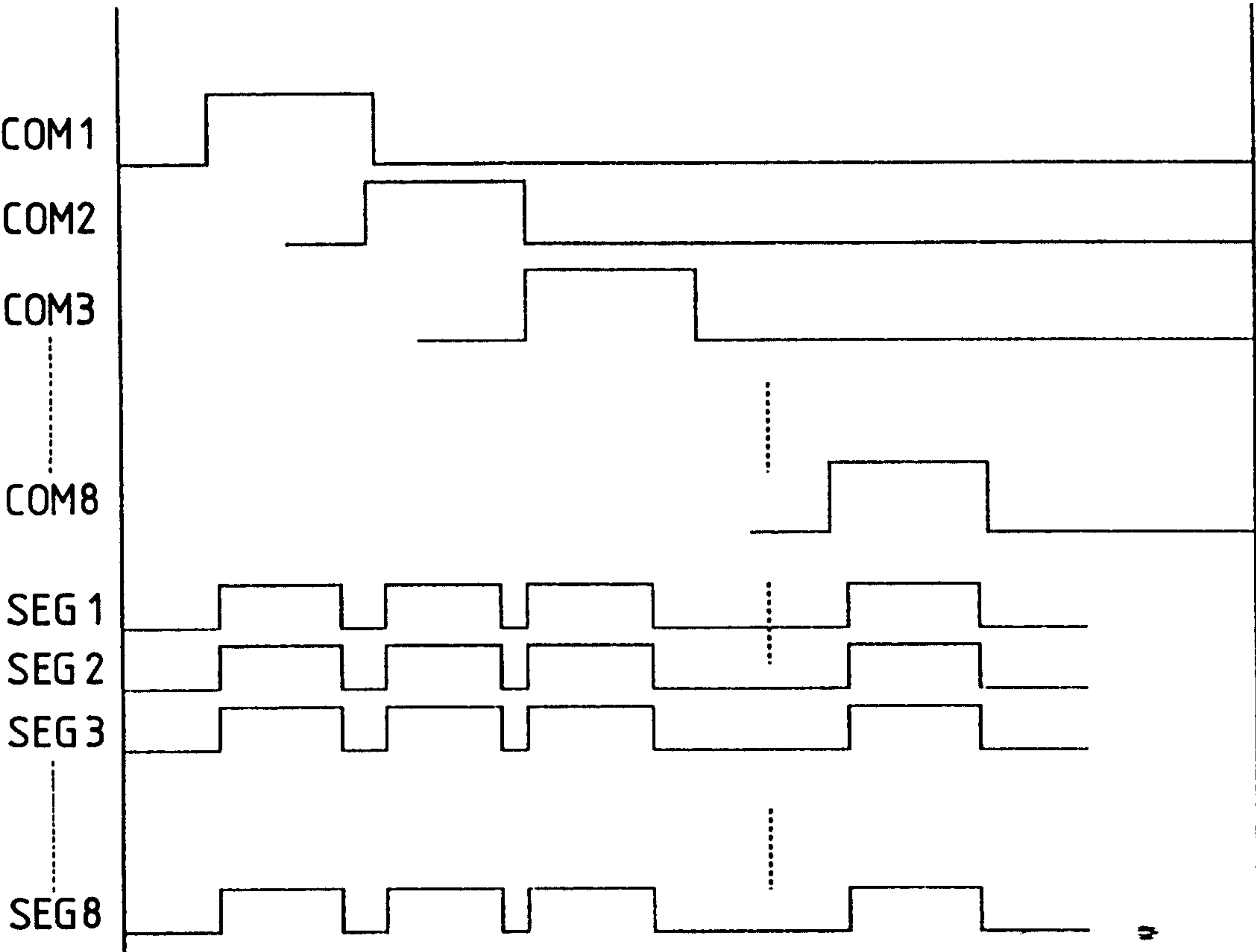


FIG. 53A

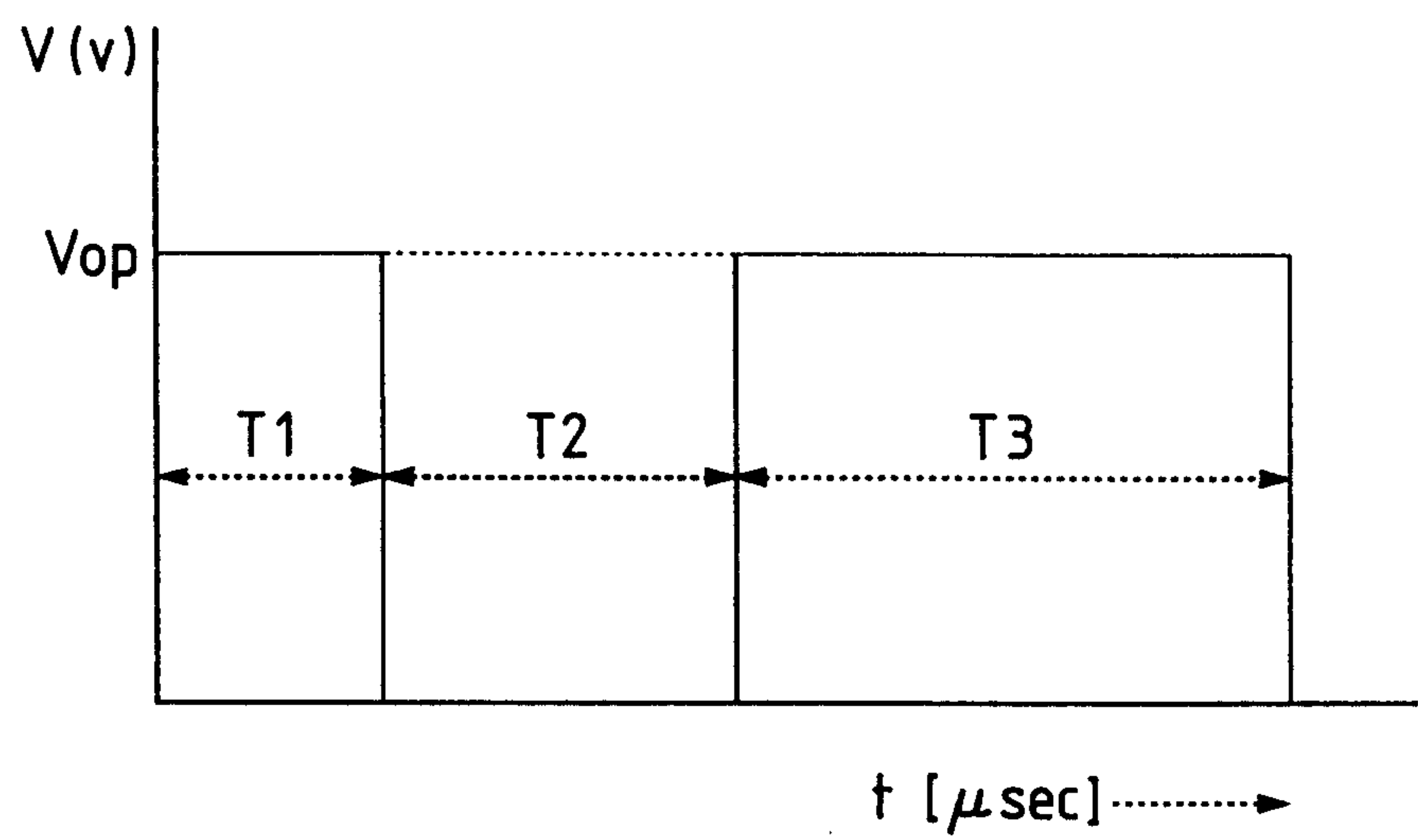


FIG. 53B

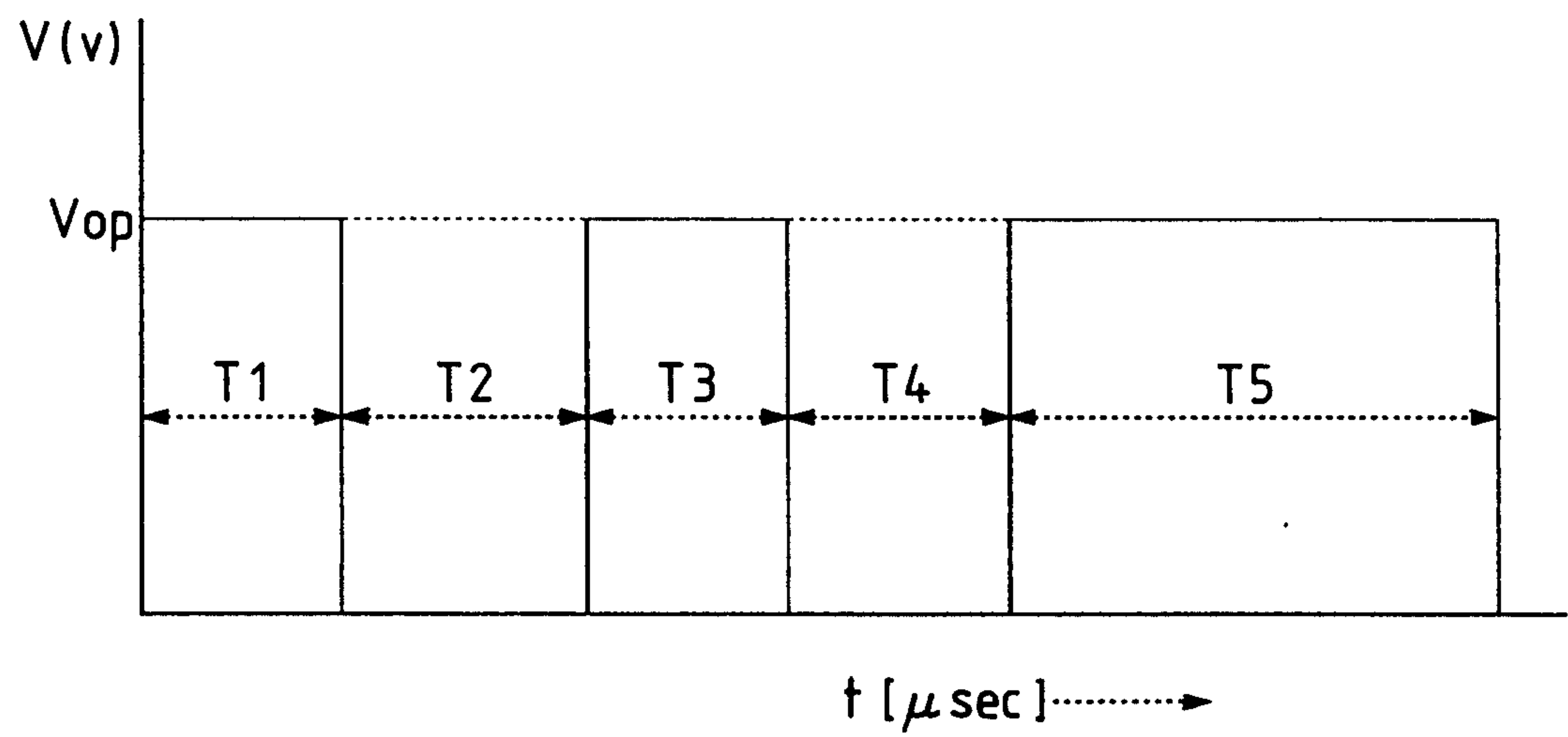


FIG. 54

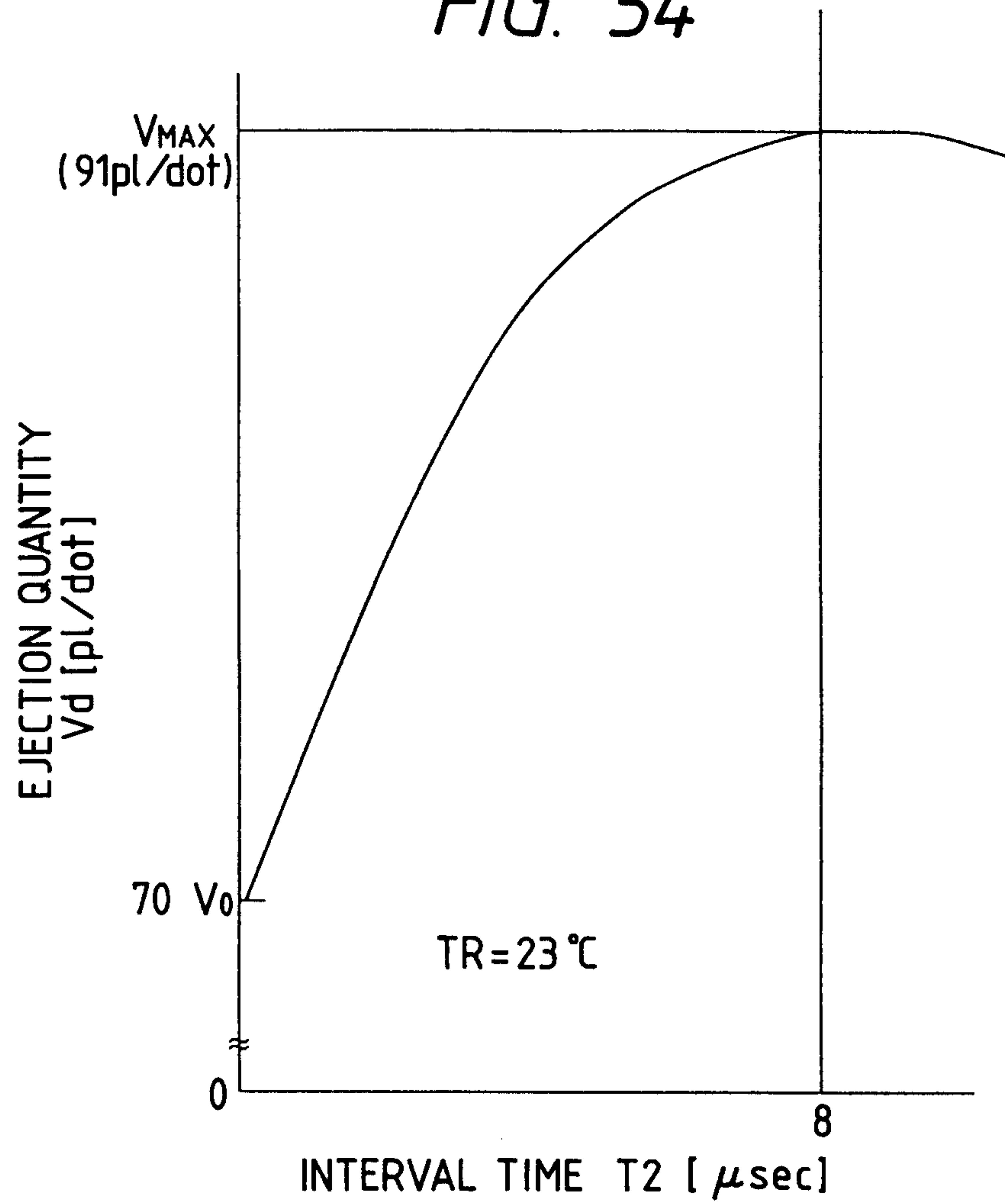


FIG. 55

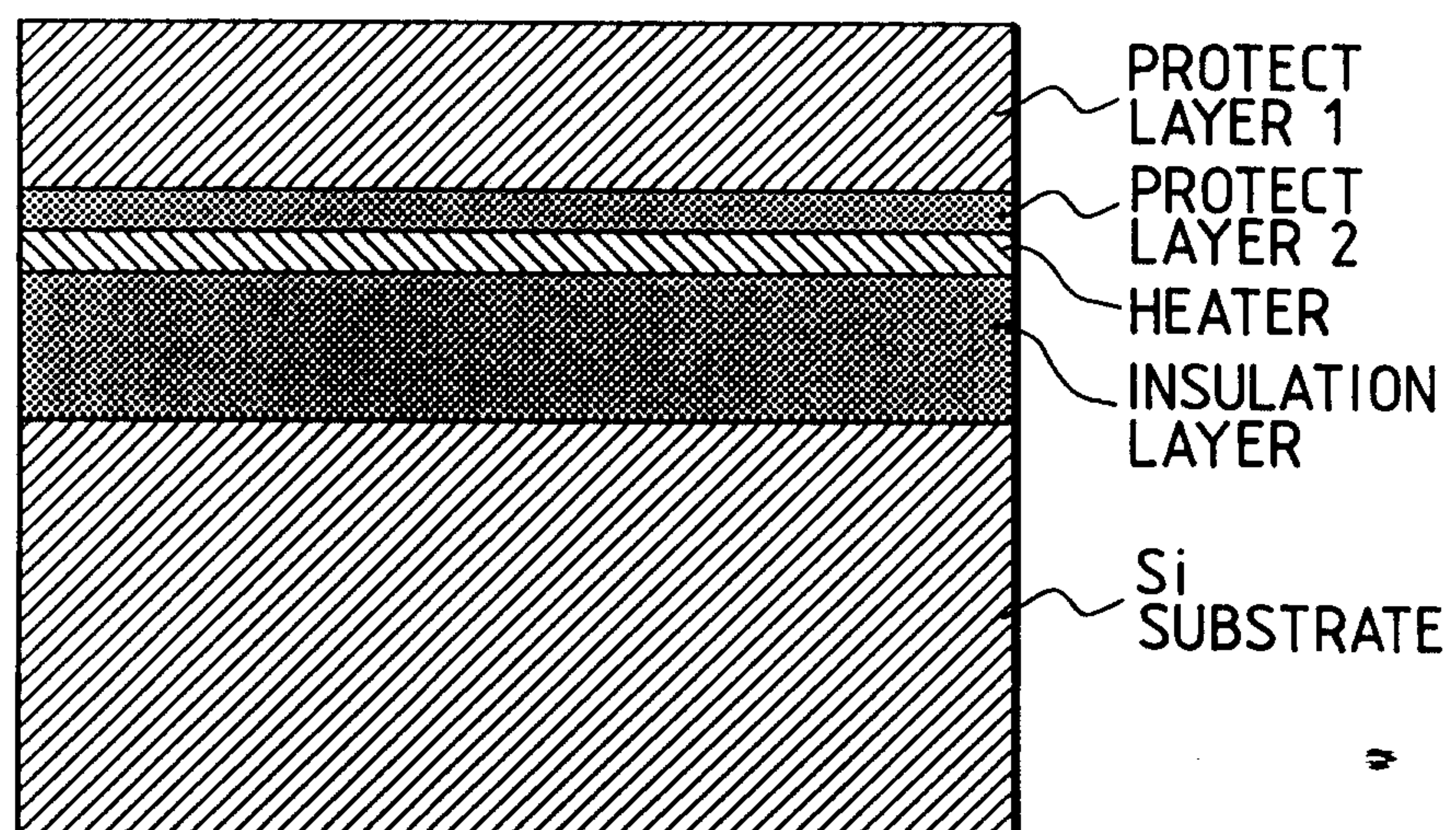


FIG. 56

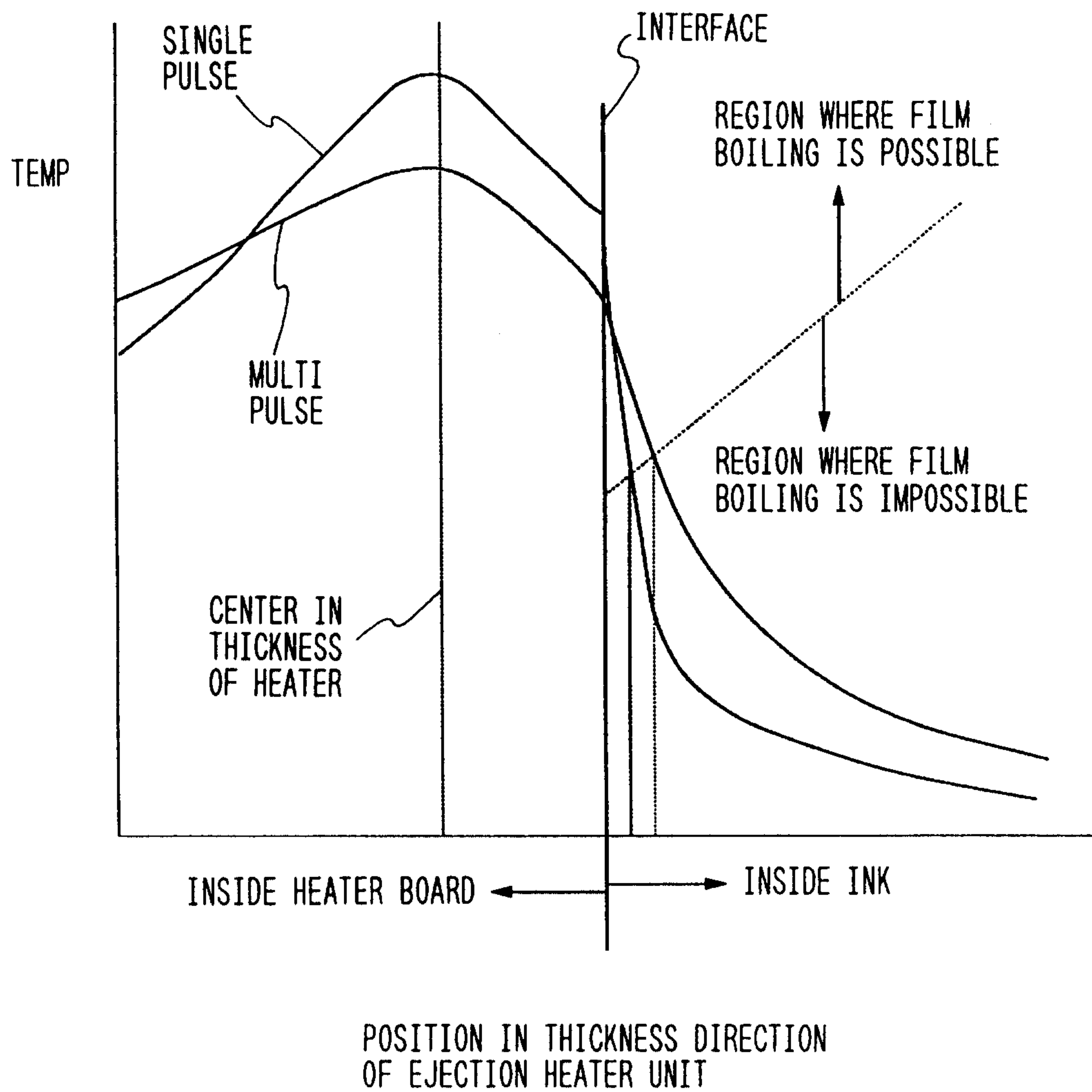


FIG. 57

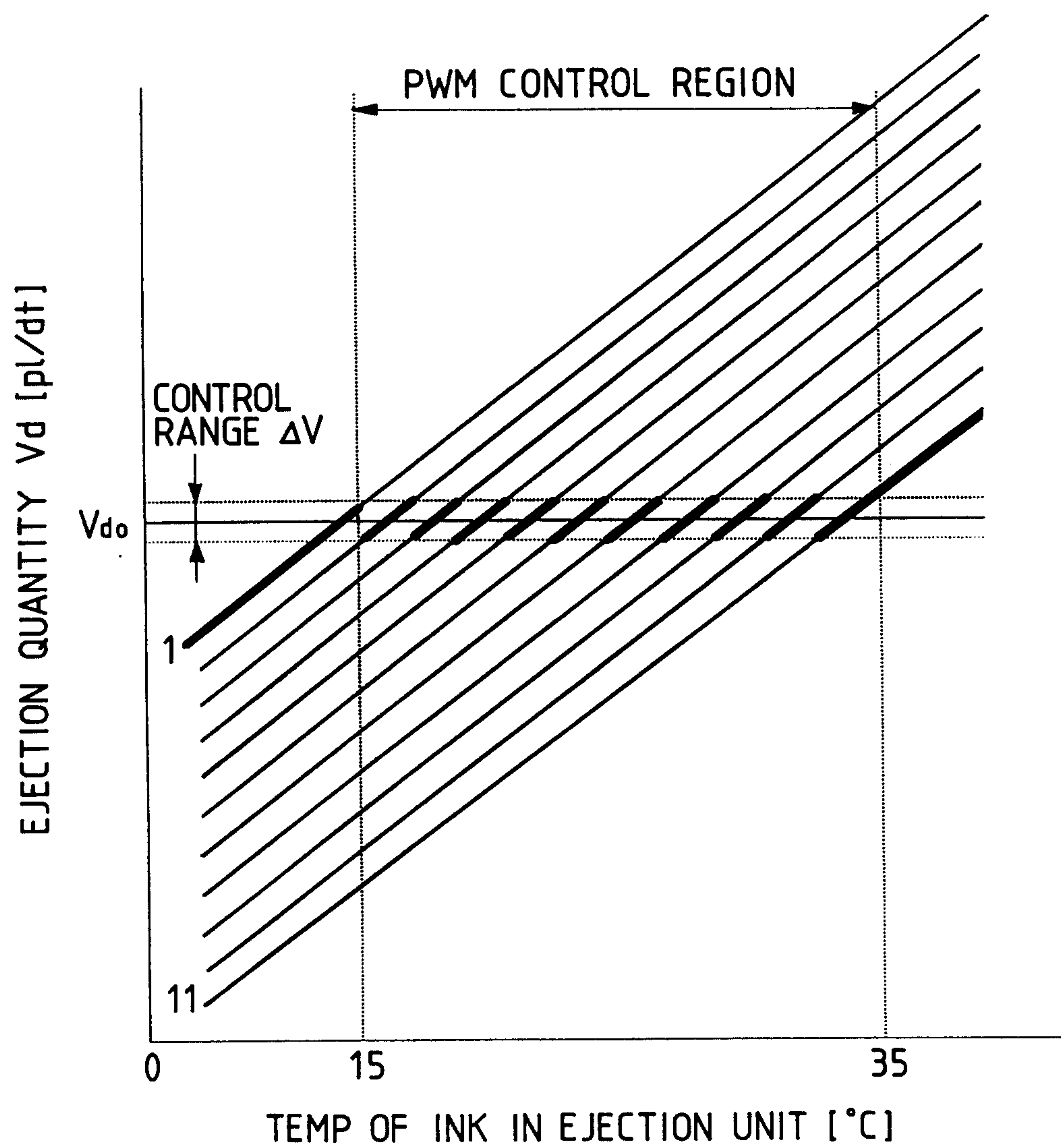


FIG. 58

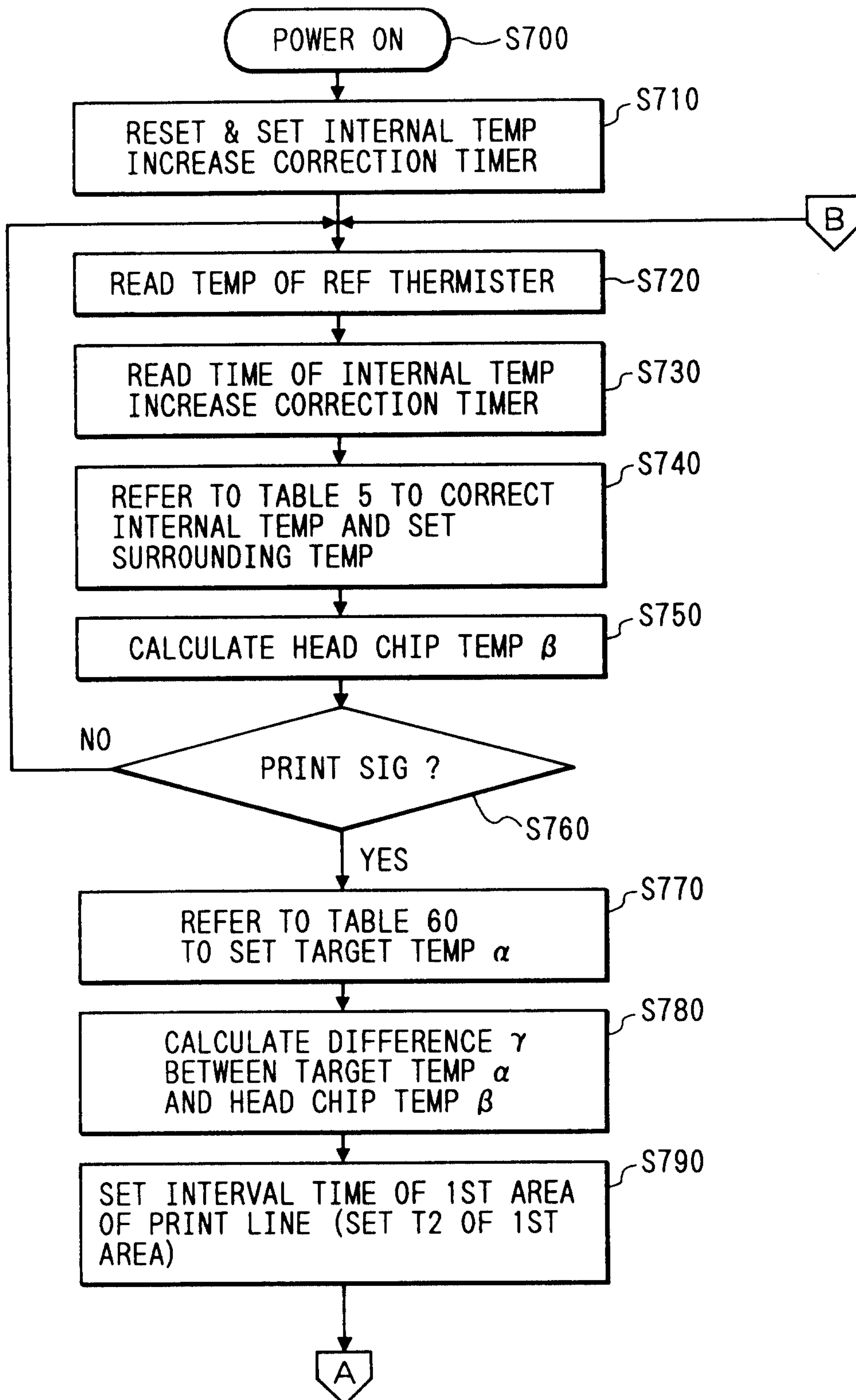


FIG. 59

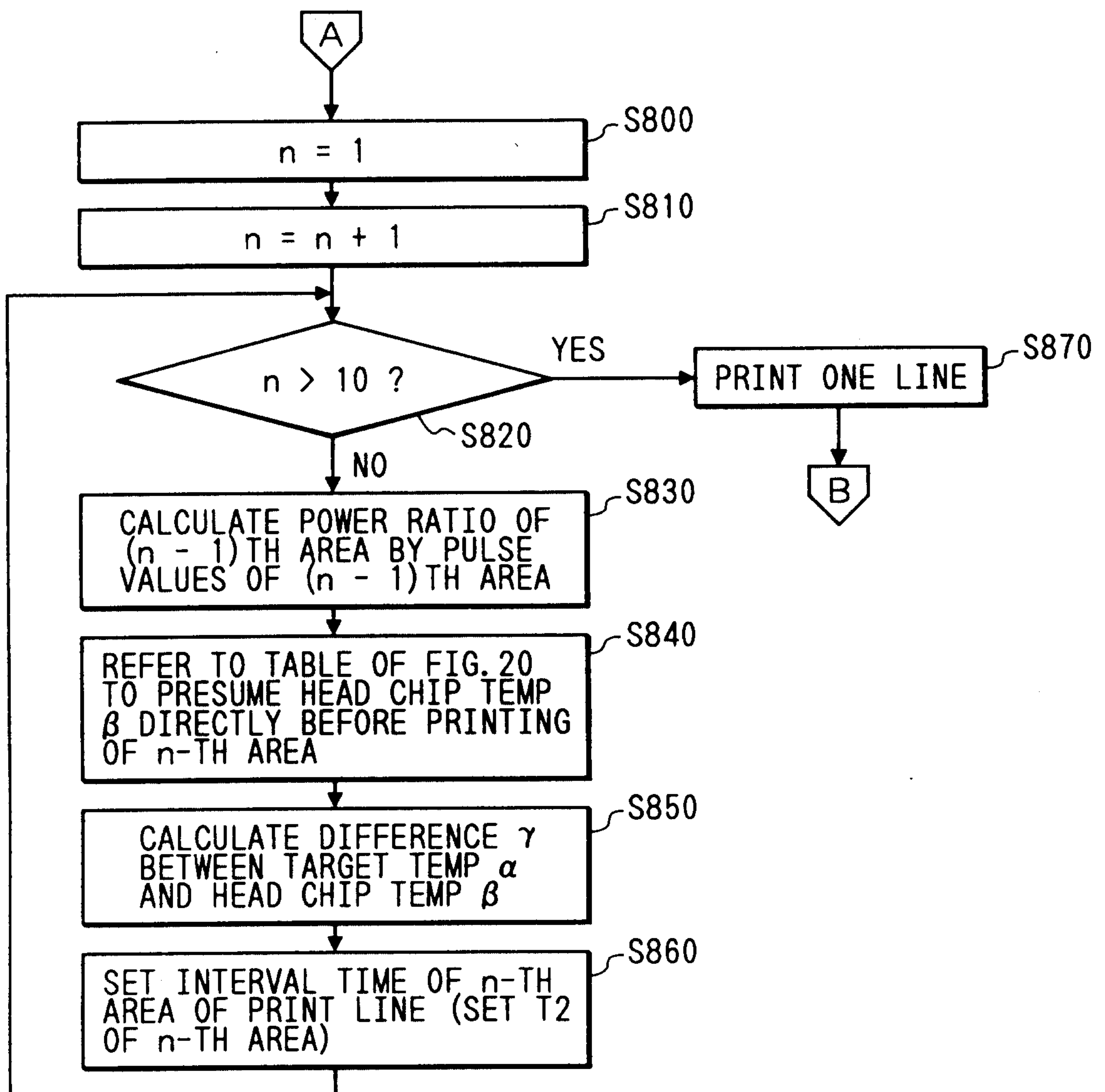


FIG. 60

SURROUNDING TEMP (°C)	TARGET TEMP (°C)
~ 12	35
12 ~ 15	34
15 ~ 18	33
18 ~ 21	33
21 ~ 24	33
24 ~ 27	32
27 ~ 30	32
30 ~	32

FIG. 62

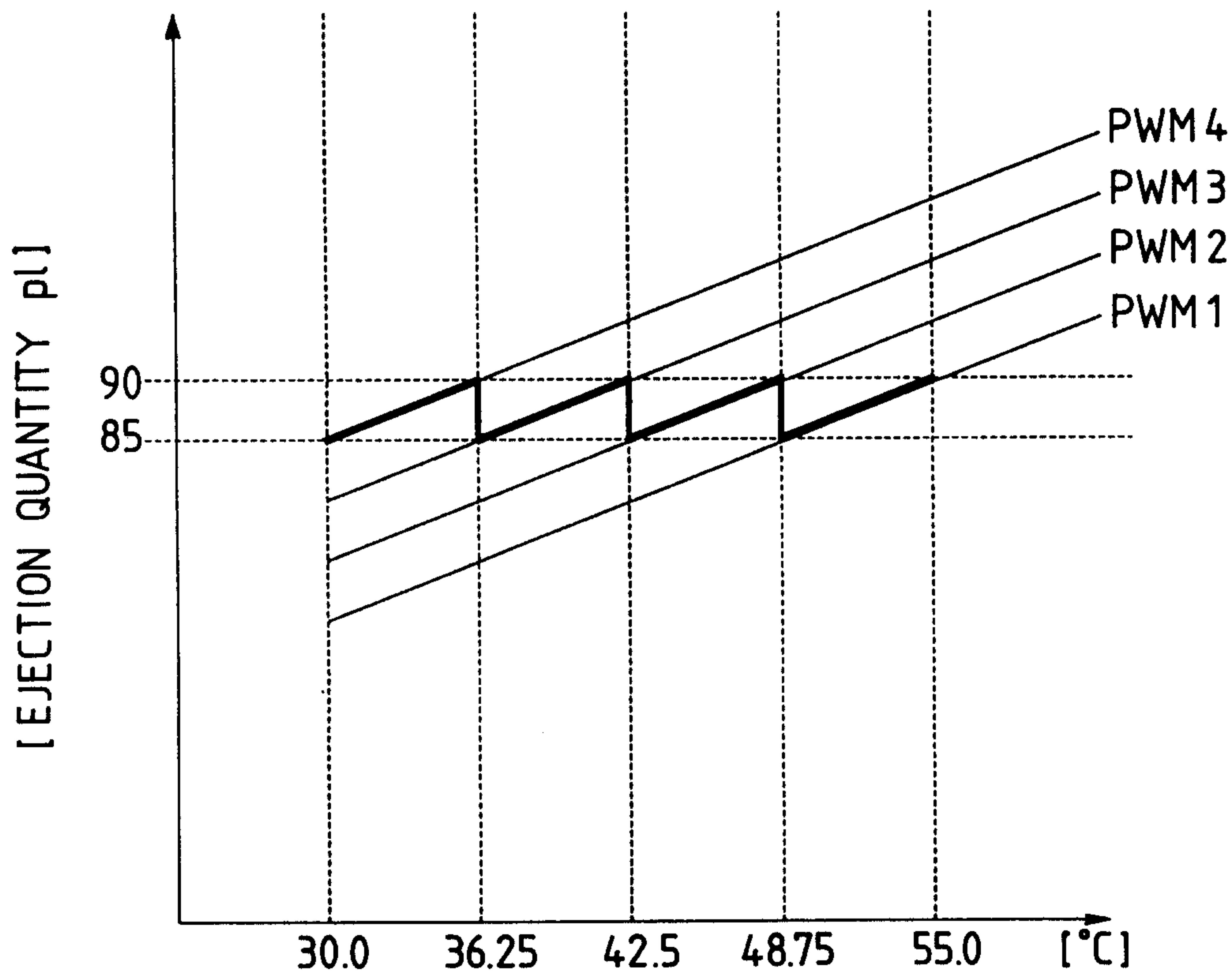


FIG. 61A

PWM RANK	DIFFERENCE (°C)	INTERVAL TIME T2 (μsec)
1	~ -18	8.0
2	-18 ~ -16	6.0
3	-16 ~ -14	4.5
4	-14 ~ -12	3.5
5	-12 ~ -10	3.0
6	-10 ~ -8	2.5
7	-8 ~ -6	2.0
8	-6 ~ -4	1.5
9	-4 ~ -2	1.0
10	-2 ~	0.0

FIG. 61B

PWM RANK	DIFFERENCE (°C)	PRE-PULSE TIME T1 (μsec)
1	~ -18	3.0
2	-18 ~ -16	2.5
3	-16 ~ -14	2.0
4	-14 ~ -12	1.5
5	-12 ~ -10	1.2
6	-10 ~ -8	1.0
7	-8 ~ -6	0.7
8	-6 ~ -4	0.4
9	-4 ~ -2	0.2
10	-2 ~	0.0

FIG. 63

	PRE-PULSE T1	INTERVAL TIME T2	MAIN PULSE T3
PWM1	2.0μsec	0.0μsec	5.0μsec
PWM2	2.0μsec	2.0μsec	5.0μsec
PWM3	2.0μsec	4.0μsec	5.0μsec
PWM4	2.0μsec	6.0μsec	5.0μsec

FIG. 65

T1 T2	2.0μsec	2.5μsec	3.0μsec
0μsec	100%	100%	100%
2μsec	117%	122%	128%
5μsec	125%	133%	142%
8μsec	130%	140%	150%

FIG. 64

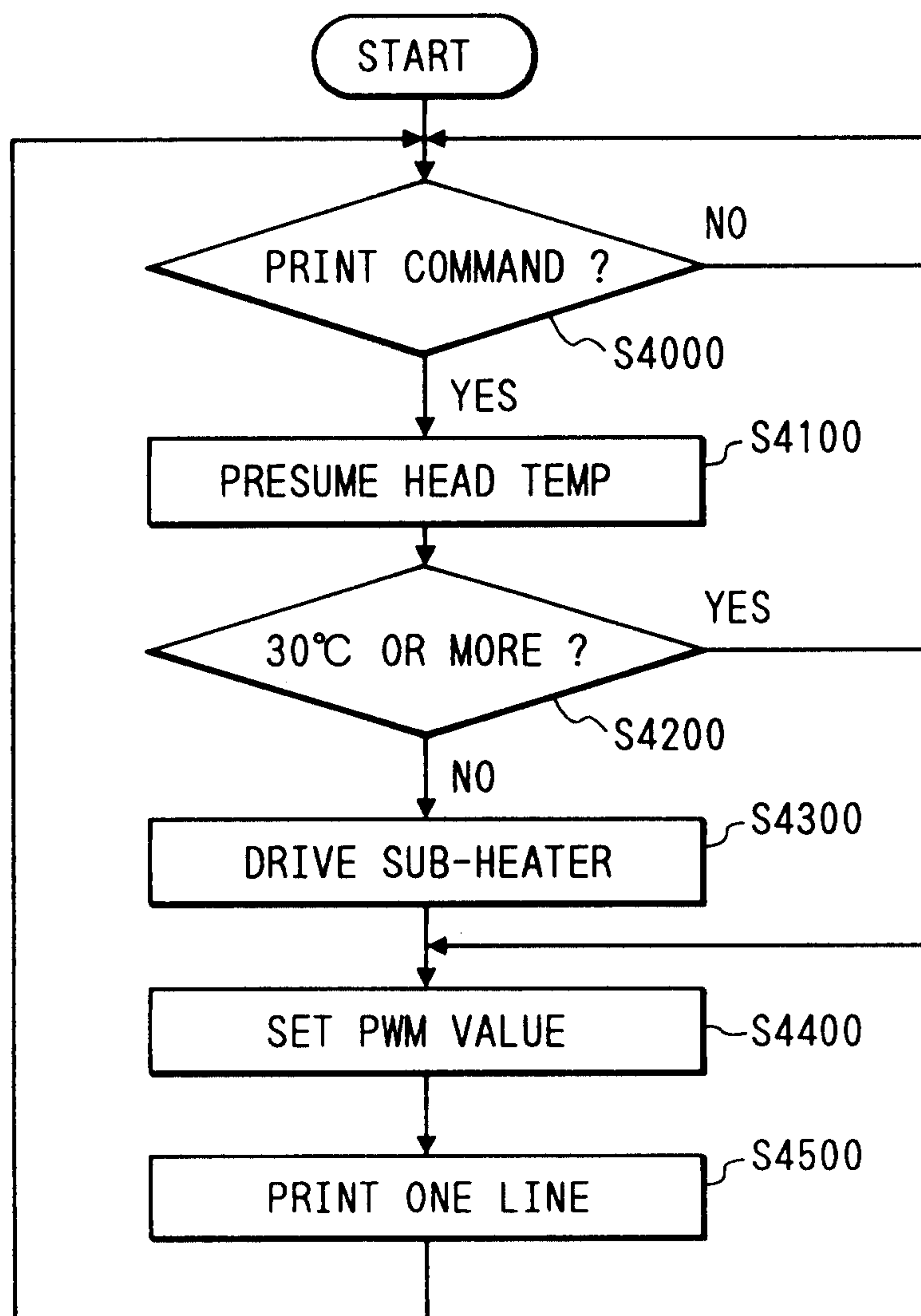


FIG. 66

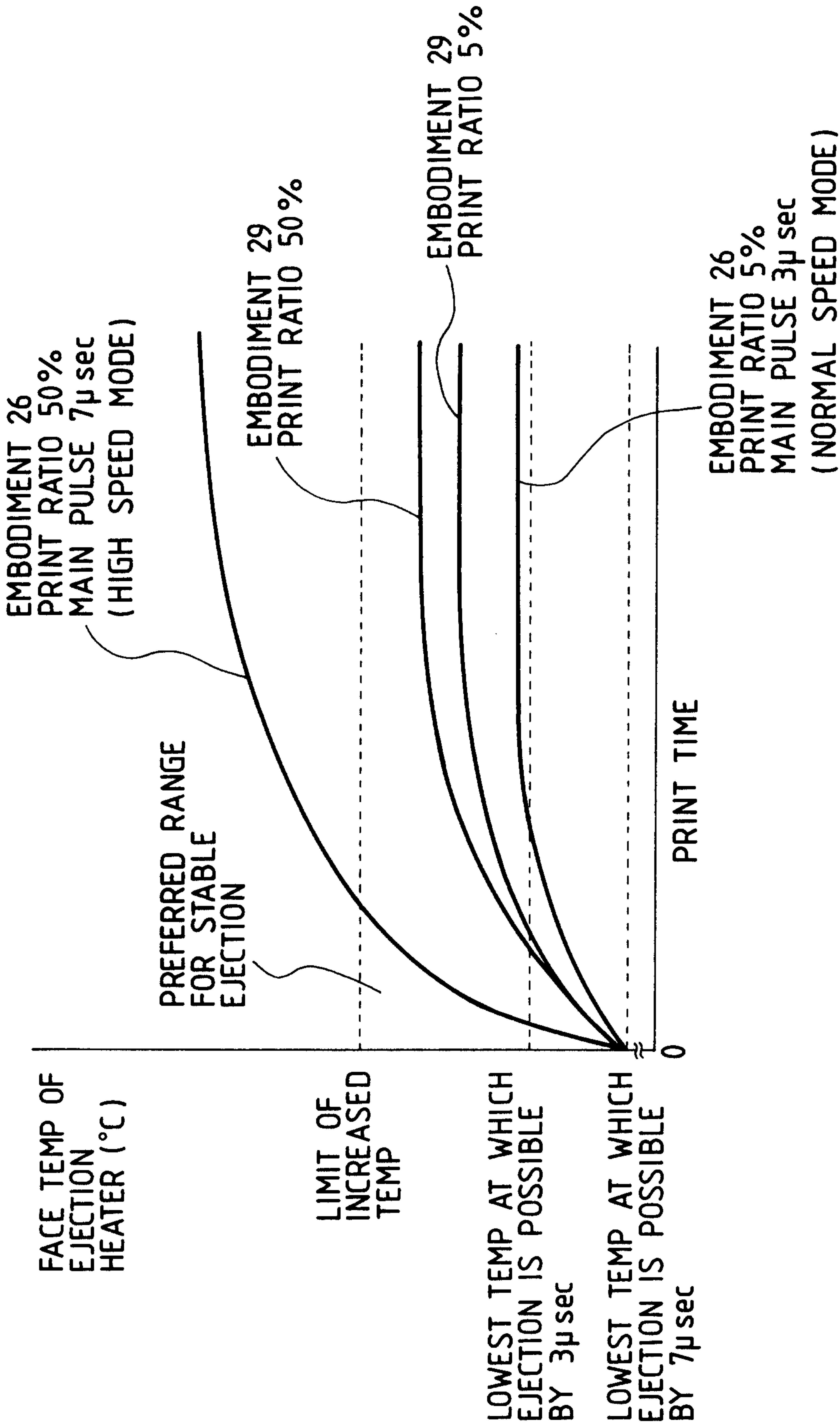


FIG. 67

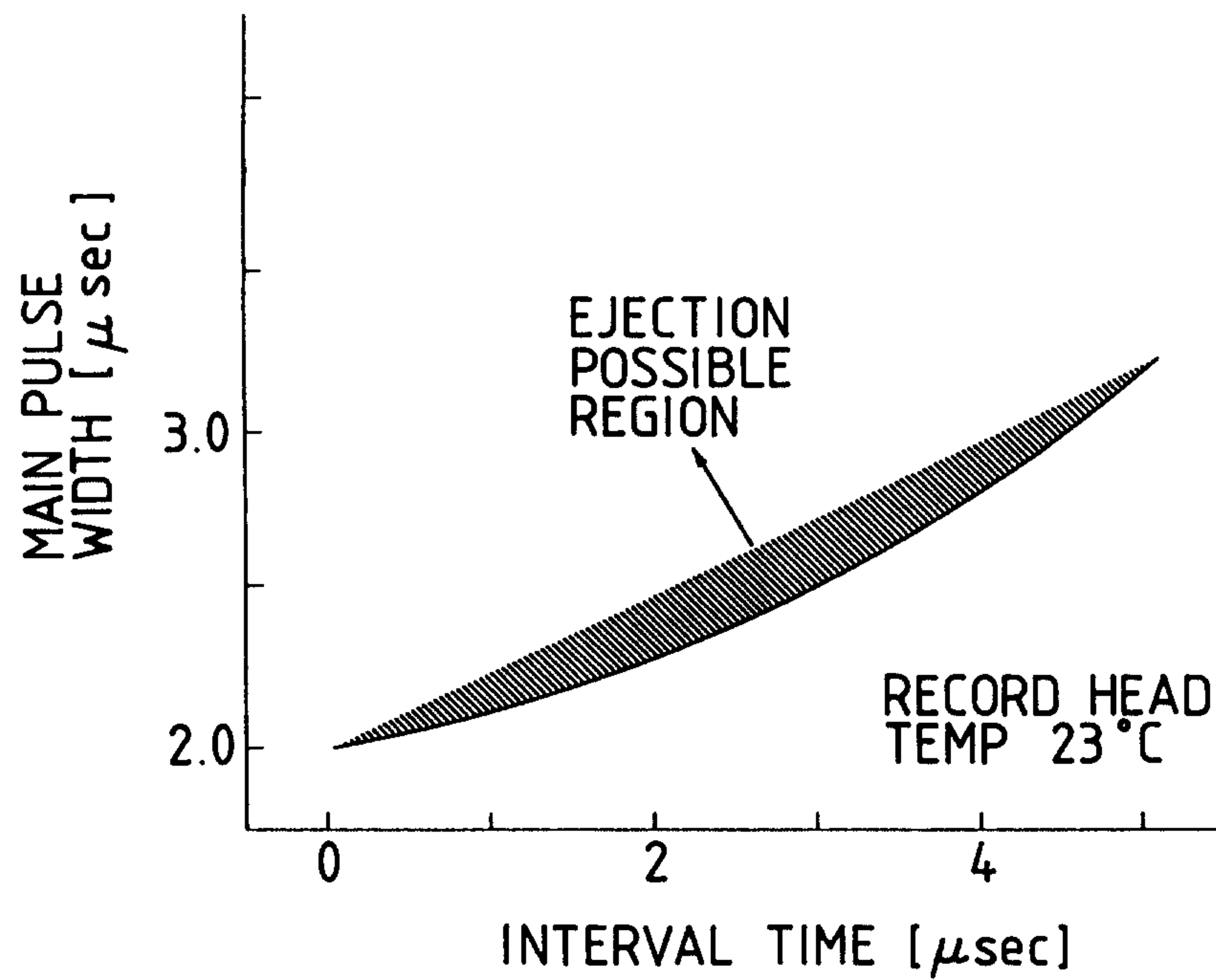


FIG. 68

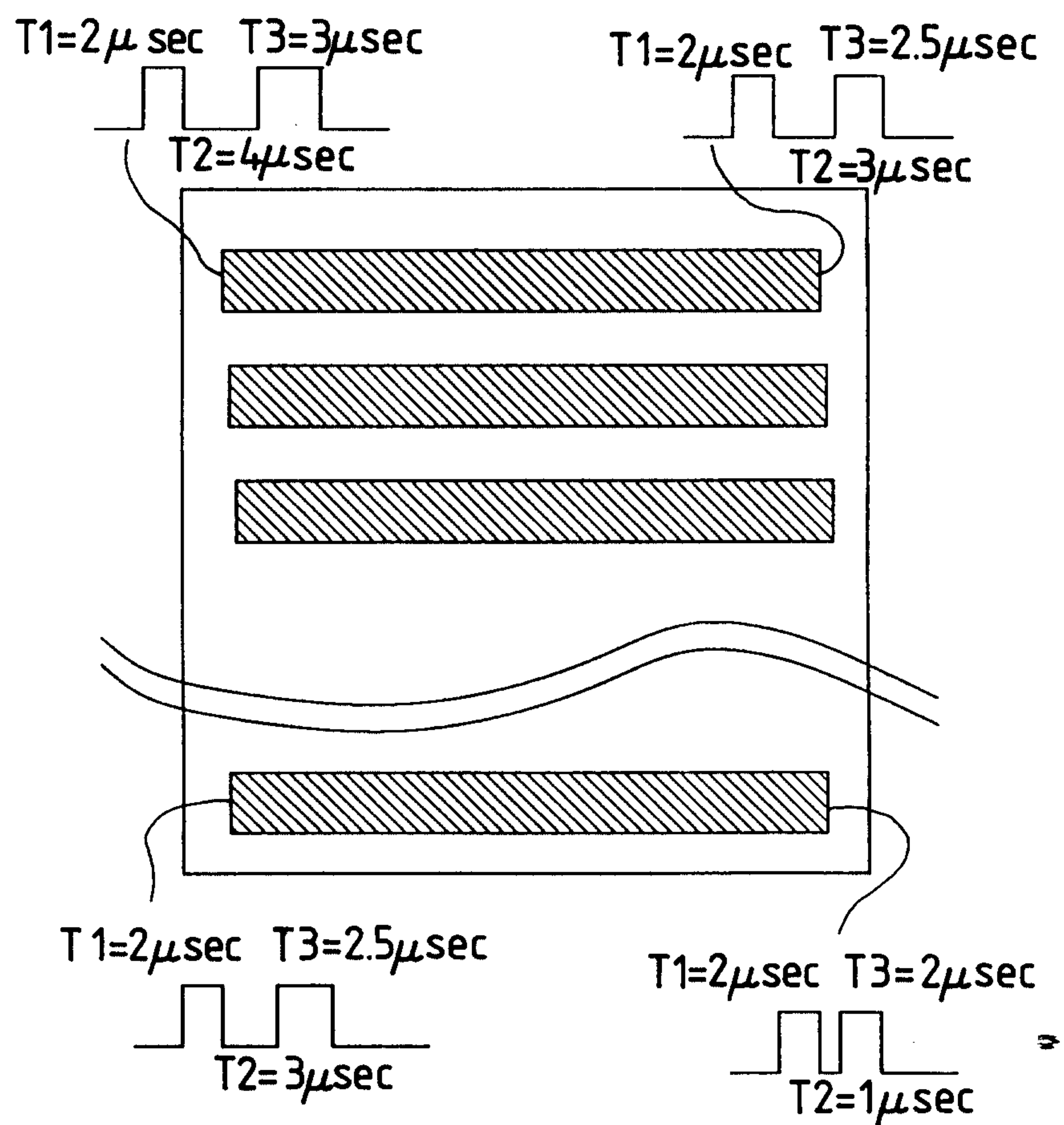


FIG. 69

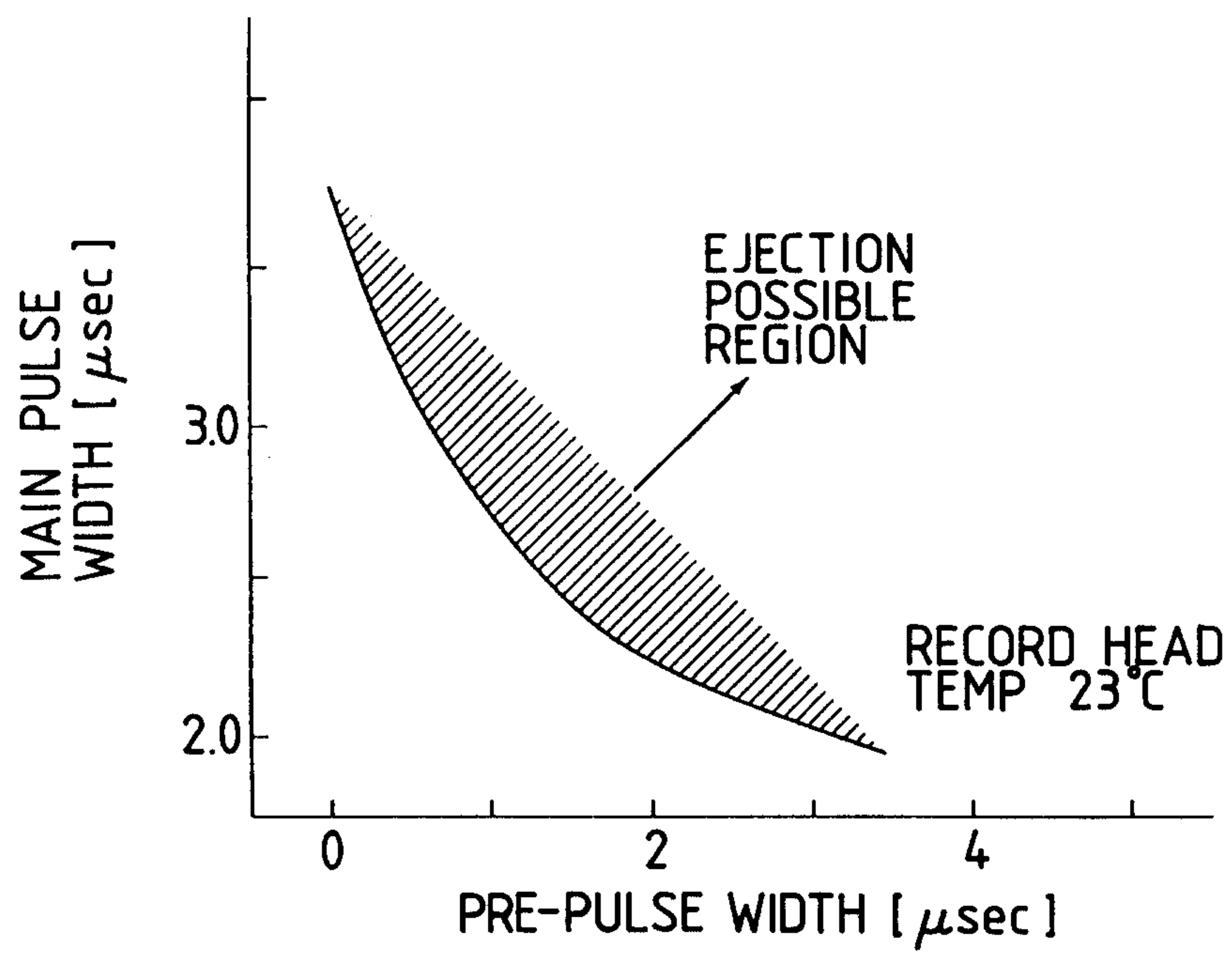


FIG. 70

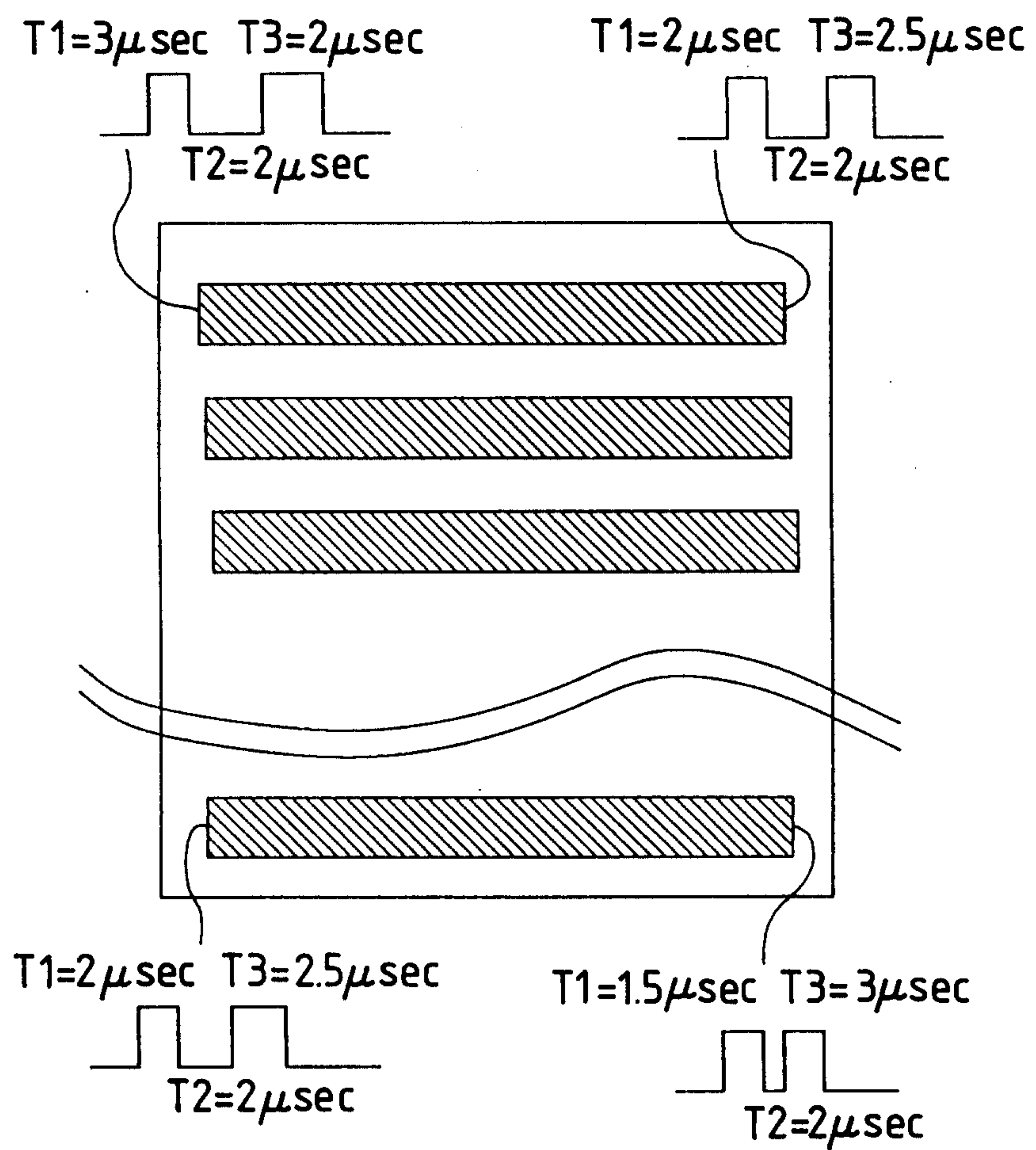


FIG. 71

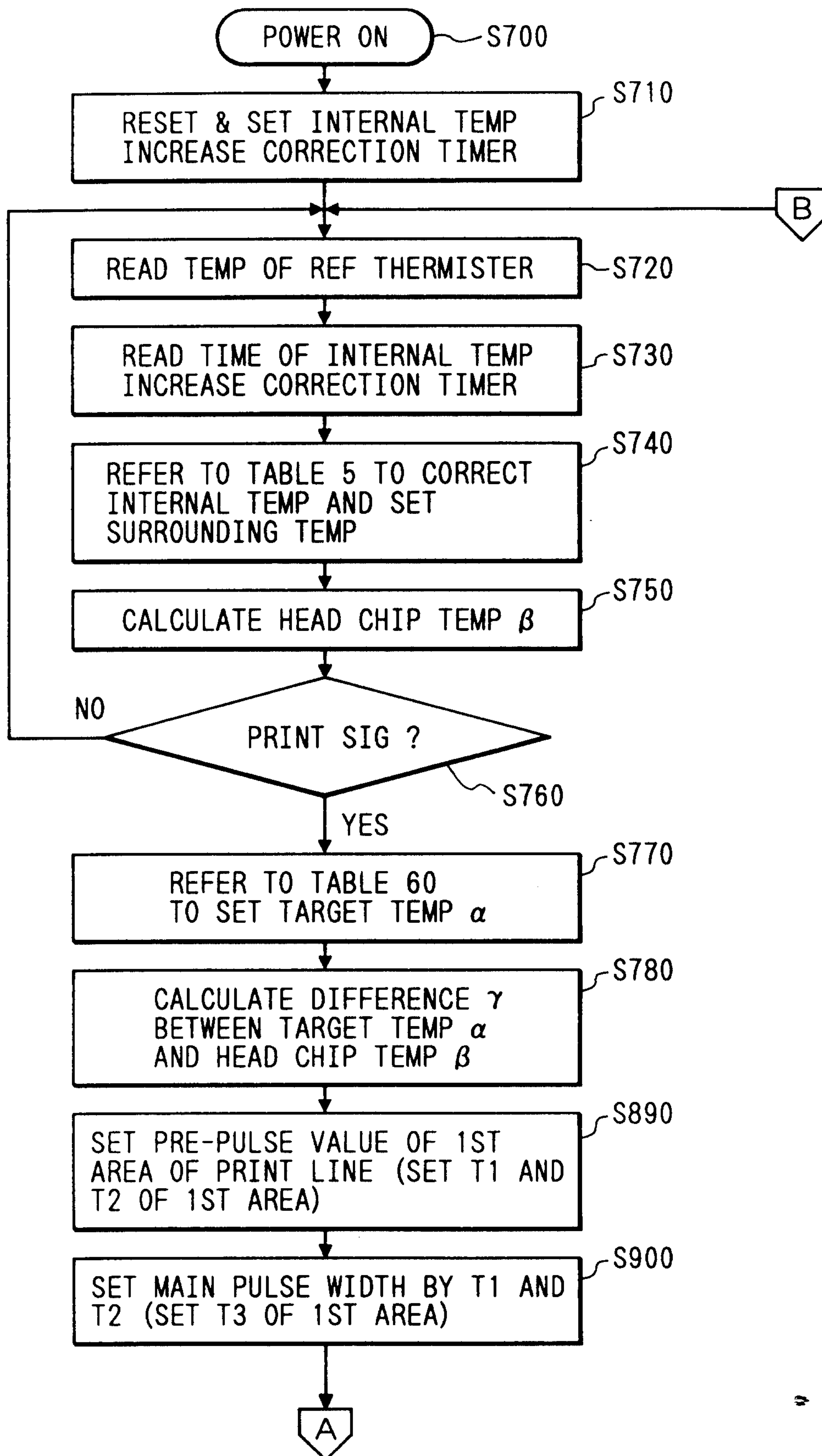


FIG. 72

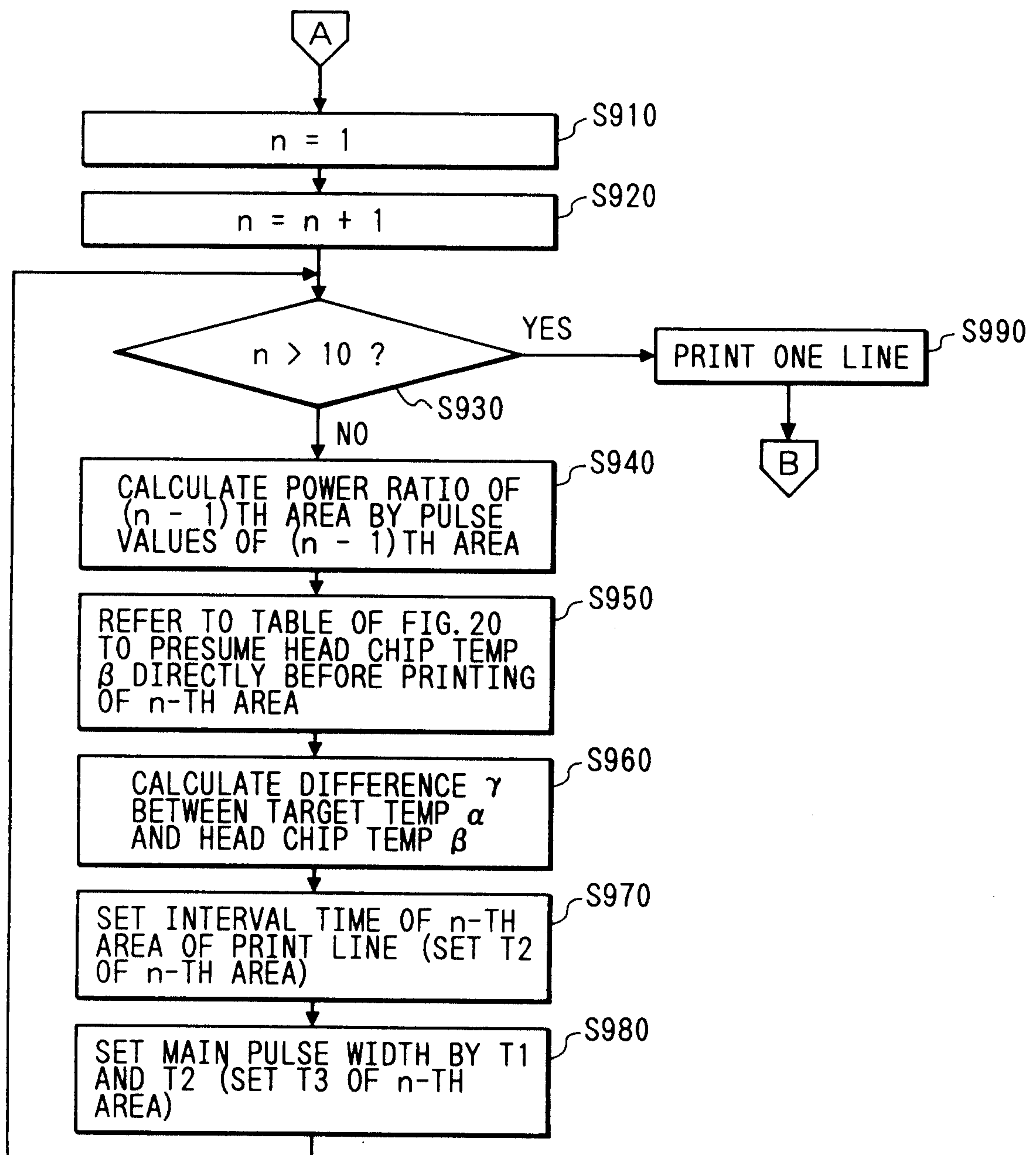


FIG. 73

INTERVAL (μ sec)	MAIN PULSE VALUE (μ sec)
5.5	5.0
5.0	4.0
4.5	3.5
4.0	3.0
3.0	2.5
2.0	2.25
1.0	2.0
0.0	3.0

FIG. 74

PRE-PULSE VALUE (μ sec)	MAIN PULSE VALUE (μ sec)
0	5.0
0.5	4.0
1.0	3.5
1.5	3.0
2.0	2.5
2.5	2.25
3.0	2.0
3.5	1.90

FIG. 75

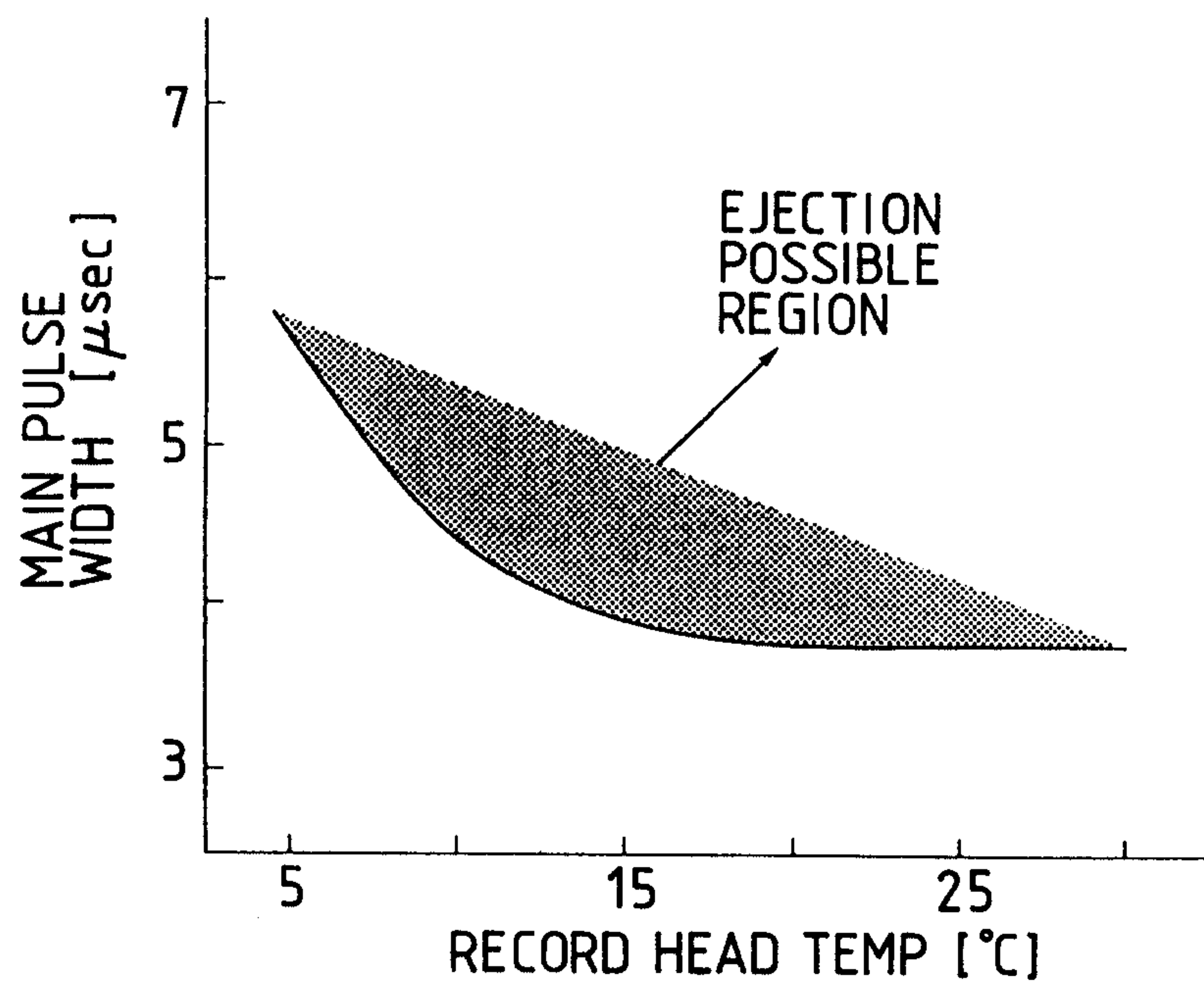


FIG. 76

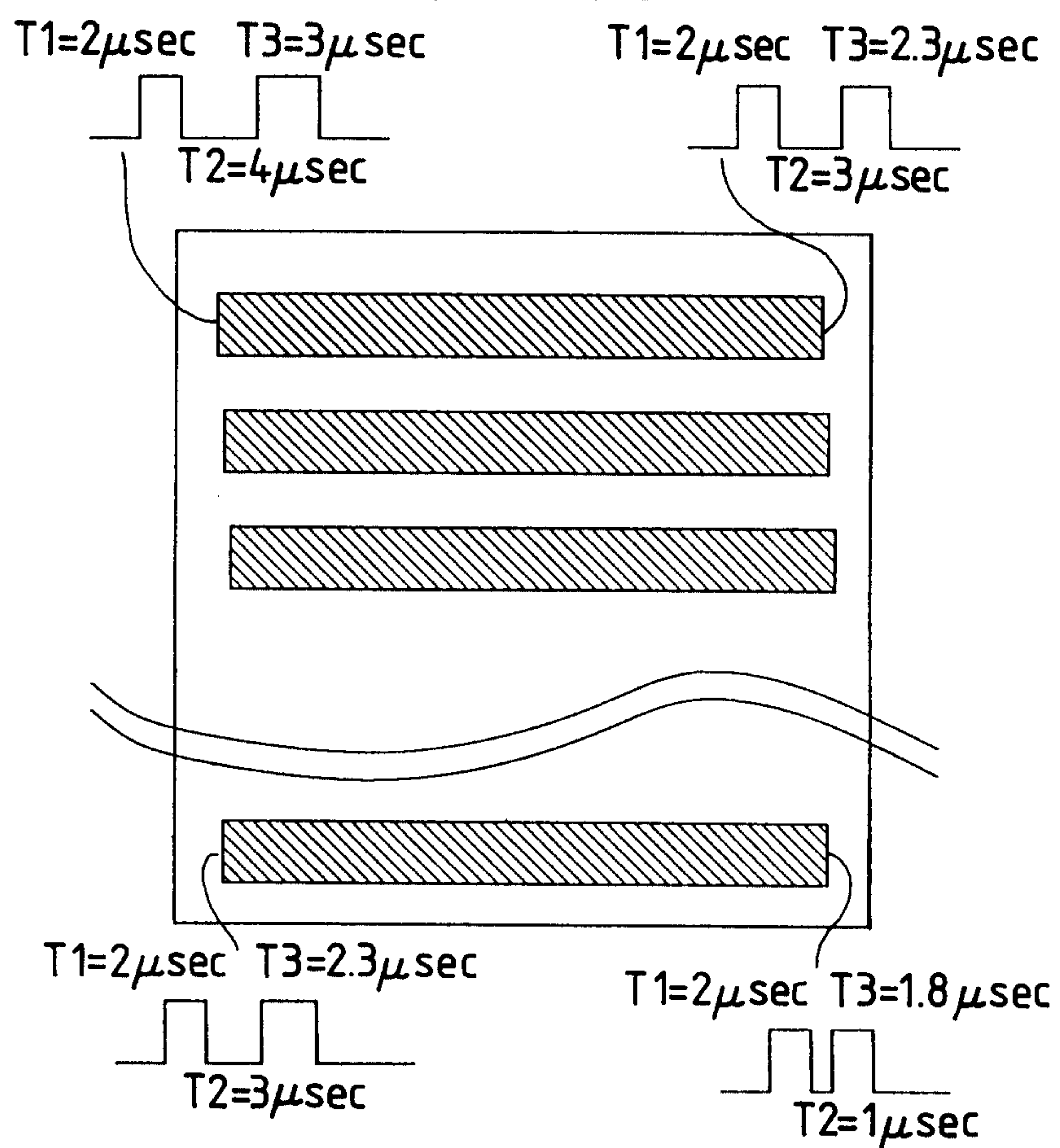


FIG. 77

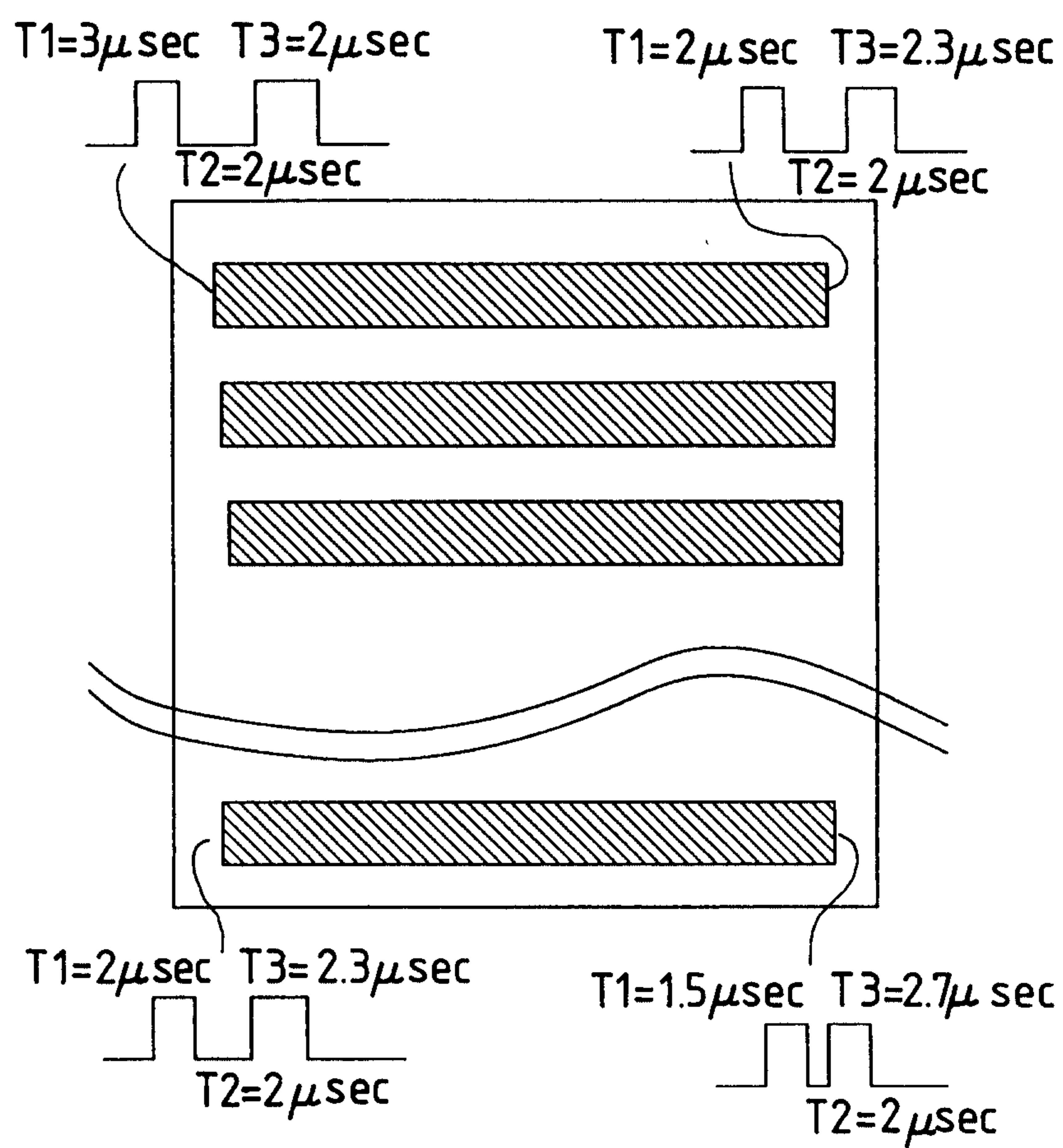
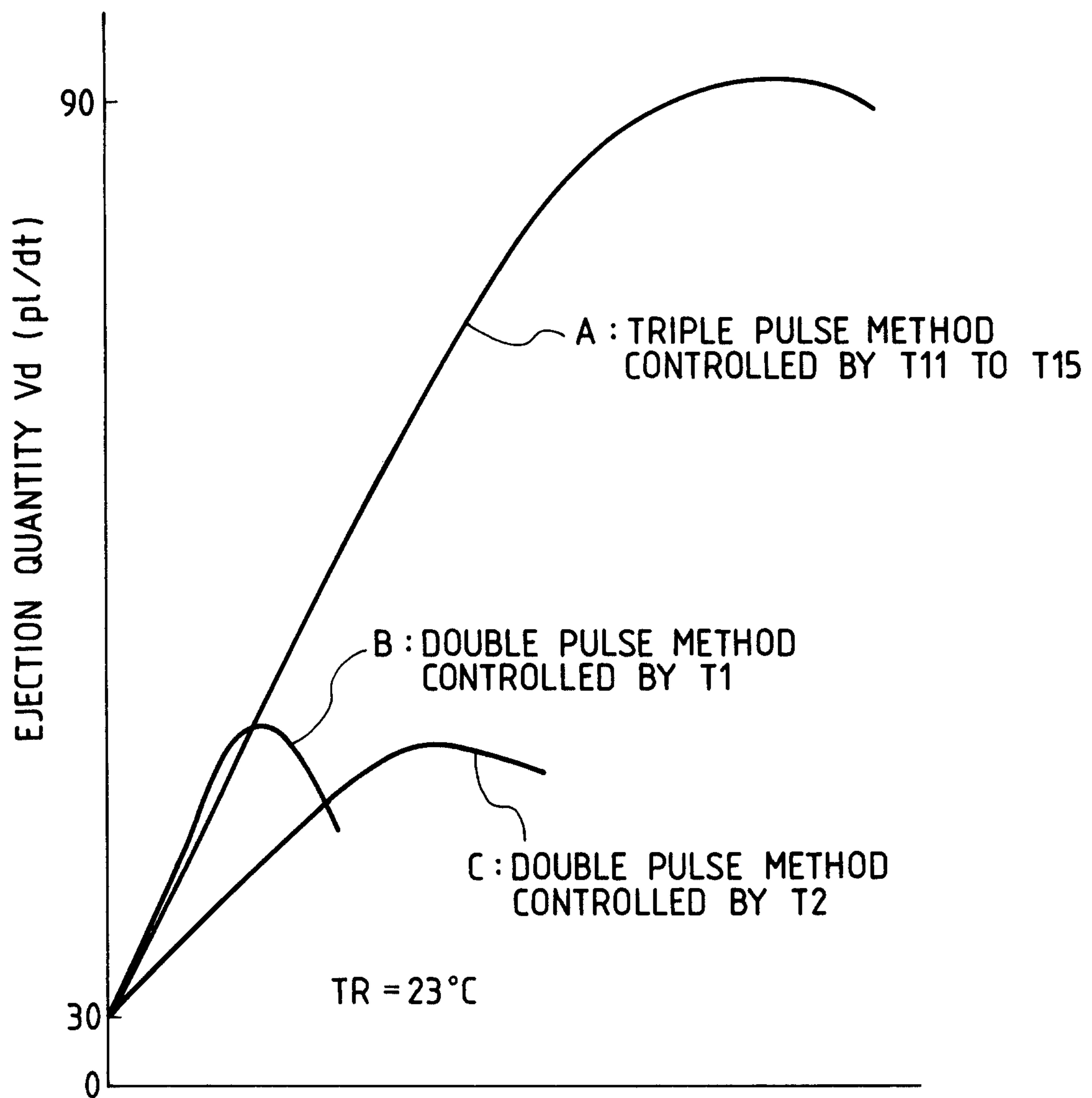


FIG. 78

PULSE WIDTH (T11 TO T15) [μsec] FOR METHOD APULSE WIDTH (T1) [μsec] FOR METHOD CPULSE WIDTH (T2) [μsec] FOR METHOD B

