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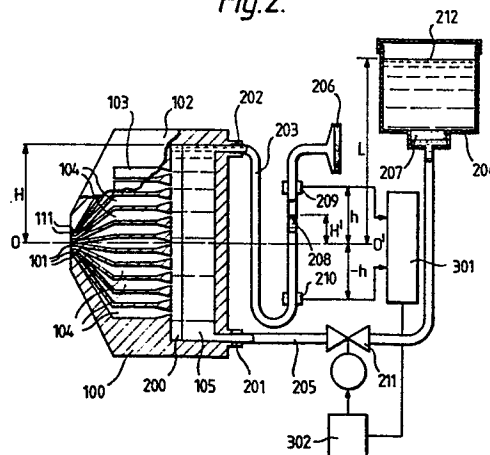
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Multi-nozzle ink-jet print head of drop-on-demand type.

A multi-nozzle ink-jet print head of the drop-on-demand type has a plurality of ink injection nozzles (101) connected to a common ink reservoir (105) via pressure chambers (104) and an ink-supply path (200) which has dimensions so small that ink is supplied from the ink reservoir (105) to the injection nozzles (101) as a result of capillary action in the supply path (200).

Fig.2.



"Multi-Nozzle Ink-jet Print Head of
Drop-on-demand Type".

This invention relates to a drop-on-demand type ink-jet print head, and more particularly to a multi-nozzle ink-jet print head having a plurality of nozzles arranged in line.

5 Various types of ink-jet printers have been proposed as described in an article entitled "Ink Jet Printing" by Fred J. Kamphoefner published in the IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. Ed-19, No. 4, April 1972, pp.584-593. An ink-jet print head of a
10 drop-on-demand type is described in detail, for example, in United States Patent No. 3,946,398 entitled "Method and Apparatus for Recording with Writing Fluids and Drop Projection means therefor" issued to E.L. Kyser et al. and in United States Patent No. 4,074,284
15 entitled "Ink Supply System and Print Head" issued to J.L. Dexter et al.

In a previously proposed multi-nozzle ink-jet print head, when an ink droplet is not ejected, ink is maintained in a state of equilibrium, so that it
20 does not flow through the nozzles, based on the balance between the static pressure of the ink in an ink reservoir and the surface tension of the ink in the nozzles. As the number of nozzles increases, the pressure difference tends to increase. This causes
25 the pressure balance to be broken, whereby the ink flows out through the nozzles. Further, when the static

pressure in the ink reservoir undergoes a change,
due to wide variations in operating conditions such
as a large change in temperature, the state of
equilibrium is broken, and the ink drips from the
5 nozzles.

Therefore, the previously proposed multi-nozzle
ink-jet print head is equipped with a pressure detector
in the ink reservoir to detect the minute pressure
change caused by the ink ejection. The output of the
10 pressure detector is used for turning an automatic
valve on or off in order to supply ink from the ink
reservoir to pressure chambers. This arrangement
complicates the print head.

Furthermore, immediately after the ejection of
15 the ink droplet, it often happens that air enters from
the nozzles to the pressure chambers. This causes a
deterioration in the printing quality.

An object of the present invention is the
provision of an ink jet print head which is less
20 likely to suffer from the undesired dripping of ink
from the nozzles than are previously proposed heads.

The object is achieved by a print head as defined
in claim 1.

A feature of the preferred embodiment of the
25 invention is the provision of a multi-nozzle ink-jet
print head of drop-on-demand type in which the ink is
maintained in a state of equilibrium based upon the
surface tension of the ink in the nozzles.

Another feature is the provision of a multi-nozzle ink-jet print head having a comparatively simple construction. ,

5 A further feature is the provision of a multi-nozzle ink-jet print head in which substantially no air enters via the nozzles to the pressure chambers.

In a preferred embodiment of this invention, there is provided a multi-nozzle ink-jet print head of the drop-on-demand type in which a plurality of
10 ink ejection channels having a plurality of nozzles and pressure chambers are connected to a common ink reservoir through an ink-supply path. The ink supply path has a dimension small enough to provide capillarity. The ink is supplied from the ink reservoir to the
15 ejection chamber owing to the capillarity.

The features and advantages of this invention will be better understood from the following detailed description of a previously proposed arrangement and preferred embodiments of the invention given by way
20 of example and with reference to the accompanying drawings, wherein:

Fig. 1 is a part-sectional side view of a previously proposed multi-nozzle ink-jet print head;

Fig. 2 is a part-sectional side view of a first
25 embodiment of this invention;

Fig. 3 is a sectional view of a part of the first embodiment shown in Fig. 2; and

Fig. 4 is a part-sectional plan view of a second embodiment of this invention.

The previously proposed multi-nozzle ink-jet printer shown in Fig. 1 comprises a plurality of ink

ejection channels having pressure chambers 104 provided between nozzles 101 and an ink reservoir 105 in a substrate 100. A thin flexible upper plate 102 made of a glass ceramic or stainless steel is adhesively fixed on to the substrate 100. Electro-
5 mechanical transducer elements 103, such as piezo-electric elements, are fastened to the upper plate 102 at positions corresponding to the pressure chambers 104.

10 When a driving voltage is applied to the electro-mechanical transducer element 103, an internal stress arises in the transducer element which causes the wall of the pressure chamber 104 to be deformed and adopt a curved shape. When the wall is curved in-
15 wardly into the pressure chamber 104, the internal volume of the pressure chamber decreases and ink within the pressure chamber is ejected from the nozzle 101 as an ink droplet.

When no driving voltage is applied, no ink
20 droplet is to be ejected from the nozzle 101, and the ink is to be maintained in a state of equilibrium based on a balance between a static pressure of the ink in the ink reservoir 105 and the pressure of ink resulting from the surface tension at the nozzle 101.
25 For instance, a difference in head pressure (head pressure difference) H of several cms of H_2O is required in order to maintain the balance in a print head having seven nozzles 101, as shown in Fig. 1. As the number of nozzles increases however, the head
30 pressure difference H tends to increase. When the head pressure difference H becomes greater than several

cms of H_2O , the balance is broken, whereby ink flows out from the nozzle, even when no driving voltage is applied.

Referring to Figs. 2 and 3, a multi-nozzle ink-jet head according to a first embodiment of this invention comprises nozzles 101, pressure chambers 104, and a common ink reservoir 105 provided on the substrate 100. There are provided capacity regions 111 of small volume between the nozzles 101 and the pressure chambers 104 to enable stable ink droplets to be formed and to prevent air bubbles entering via the nozzles 101 to the pressure chambers 104. Between the pressure chambers 104 and the ink reservoir 105, there is an ink-supply path 200 of small depth. The ink-supply path 200 is formed by etching and has a depth 12 of about 0.04 to 0.4 mm. Owing to the capillarity of the path 200, ink can be supplied satisfactorily from the common ink reservoir 105 to the respective ink ejection channels, each of which comprises the pressure chamber 104, the capacity region 111, and the nozzle 101.

The ink, which is supplied from an ink tank 204, is temporarily stored in the ink reservoir 105 before rising through the ink supply path 200, owing to capillary action, and passing to the pressure chamber 104. After the ink droplets are ejected from the nozzles 101, by means of the pumping action of the pressure chamber 104, ink of an amount corresponding to the amount ejected is supplied through the ink supply path 200 to the pressure chamber 104. Therefore, ink can be supplied without being affected by variations in the static pressure of ink in the ink reservoir 105. This means that the number of the

nozzles can be increased considerably compared with known arrangements.

Because the ink reservoir 105 operates only to store the ink temporarily, it is unnecessary to control the static pressure of ink exactly and it is possible to employ a simplified control system.

As the frequency of the driving voltage is increased, the variation in pressure in the pressure chamber 104 is increased, whereby the entry of air bubbles from the nozzles is rendered more likely. Air bubbles which might enter via the nozzles 101, however, remain in the capacity regions 111, and are thereby prevented from entering the pressure chambers 104. This means that the pressure chambers 104 can operate normally. The air bubbles remaining in the capacity region 111 can be easily pushed out by repeating the ejecting operation, thereby increasing the droplet forming frequency to about 3000 dots/sec.

Referring to Fig. 3, assuming that the depths of the pressure chambers 104, the ink supply path 200 and the ink reservoir 105 are represented by l_1 , l_2 and l_3 , respectively, experiments show that it is ideally desirable to satisfy the following relationship:

$$\begin{aligned} l_3 &> l_2 \geq l_1 \\ l_1 &= 0.04 \text{ to } 0.4 \text{ mm} \\ l_2 &= 0.04 \text{ to } 0.4 \text{ mm} \\ l_3 &= 0.5 \text{ to } 3 \text{ mm.} \end{aligned}$$

It is also desirable to make the pressure chambers 104 and the ink supply path 200 have the same depth

from the viewpoint of etching cost. Further, in our experience, the best practical result is obtained when the ink supply path 200 has a depth l_2 of 0.05 to 0.2 mm and a width w of 0.5 to 3 mm.

Furthermore, it is desirable for the capacity region 111 to have a width of 1.3 to 3 times as wide as that of the nozzle 101 and a length of 1.0 to 8.0 mm. The best practical result has been obtained with a width of 0.13~0.3 mm and a length of 1.0~5.0mm.

Referring again to Fig. 2, the first embodiment further comprises an air vent 202 to which one end of a liquid level meter 203 is connected. The other end of the liquid level meter 203 is open to the air through a mesh filter 206 having a mesh opening of about 5 μ m. Such a mesh filter may be provided in an outlet 207 of the ink tank 204 to prevent particles entering into the ink within the ink reservoir 105.

The height of the surface 208 of ink in the liquid meter 203 represents the head pressure of the ink in the pressure chamber 104 and the ink reservoir 105. A difference in height between the nozzles 101 and the ink surface 208 represents the head pressure difference H' of the ink in the ink reservoir 105. Assuming that a permitted head pressure difference is represented by h , when the static pressure of the ink in the ink reservoir 105 balances with the ink surface tension in the nozzle 101 so that ink does not flow out from the nozzle 101, it is necessary to set the head pressure difference H' within the range of $\pm h$. For this purpose, upper and lower level sensors 209 and 210 are positioned at upper and lower positions spaced apart

by h and $-h$ respectively from the reference level
0-0' representing the height of the nozzles 101. Each
of the level sensors 209 and 210 may be constituted
by two electrodes positioned apart from each other,
5 or a combination of a light emitting diode (LED)
and a photo transistor.

The sensors 209 and 210 are coupled to a liquid
level controller 301, which is connected to a valve
driver 302. The valve driver 302 drives a valve
10 211 such as an electromagnetic valve to control the
ink supply from an ink tank 204 to the ink reservoir
105 as will be described hereinafter.

Because the ink tank is positioned, in the first
embodiment, so that the ink surface 212 in the ink
15 tank 204 is higher than the reference level 0-0'
by L to provide a head pressure different $L-H'$, the
ink in the ink tank 204 can be supplied to the ink
reservoir 105 without using ink pressure means such
as a pump.

20 At the start of an operation, when the ink surface
208 is positioned in the range between the sensors
209 and 210, that is when it does not reach to the
position of the sensor 209, the controller 301 controls
the valve driver 302 to turn on the valve 211 so that
25 ink is supplied from the ink tank 204 through the
pipe 205 and an inlet channel 201 to the ink reservoir
105, thereby to increase the static pressure in the
ink reservoir 105. As the static pressure increases,
the ink surface 208 becomes higher. When the ink
30 surface 208 reaches to the position of the upper sensor
209, the controller 301 causes the valve driver 302 to

turn off the valve 211 so that the supply of ink is stopped, thereby to stop the static pressure increasing.

By ejecting the droplets during printing, the static pressure is decreased and the ink surface 208 is lowered. When the ink surface 208 reaches the position of the lower sensor 210, the controller 301 again controls the valve driver 302 to turn on the valve 211. This operation is repeated to maintain the head pressure difference H' in the range of $\pm h$.

Referring to Fig. 4, the second embodiment includes a liquid level sensor 401 having electrodes 401A and 401B, arranged spaced apart from each other in the ink reservoir 105, and a valve controller 402, instead of the sensors 209 and 210 and the combination of the controller 301 and the valve driver 302 employed in the first embodiment, respectively. When the liquid level is lower than the position of the electrode 401A, the controller 402 causes the valve 211 to be turned on, thereby to supply ink from the ink tank 204 to the ink reservoir 105.

It will be appreciated that, although the invention has been described, by way of example, with reference to particular embodiments, it is possible to employ variations and modifications within the scope of the invention claimed. For example, the capacity regions 111, which act as a buffer or store between the nozzles 101 and the pressure chambers 104, may incorporate features designed to inhibit still further the entry of air and any unwanted outflow of ink.

CLAIMS

1. An on-demand type, ink-jet print head for ejecting ink droplets, the print head including:

a plurality of nozzles (101) for ejecting ink droplets;

5 an ink reservoir (105); and

a plurality of pressure chambers (104) provided between the nozzles (101) and the ink reservoir (105) for exerting pressure on ink supplied from the ink reservoir (105) to eject ink droplets from the nozzles (101); characterised in that between the pressure chambers (104) and the ink reservoir (105) there is provided an ink supply path (200) for supplying ink from the ink reservoir (105) to the pressure chamber by means of capillarity.

15 2. A print head as claimed in claim 1, characterised in that the depth of the ink supply path (200) is less than that of the ink reservoir (105).

3. A print head as claimed in either claim 1 or claim 2, characterised in that the ink supply path (200) has a depth of 0.04~0.4mm.

4. A print head as claimed in any one of the preceding claims, characterised in that the depths l_1 , l_2 and l_3 of a nozzle (101), the ink supply path (200) and the ink reservoir (105) have the following relationship:

$$l_3 > l_2 \geq l_1 .$$

5. A print head as claimed in claim 4, characterised in that the depths l_1 , l_2 and l_3 are from 0.04 to 0.4mm, from 0.04 to 0.4 mm and from 0.5 to 3 mm, respectively.

6. A print head as claimed in any one of the preceding claims characterised in that there are provided capacity regions (111) between the nozzles (101) and the pressure chambers (104), the capacity regions being
5 smaller in dimension than the pressure chambers (104).

7. A print head as claimed in any one of the preceding claims characterised in that there is provided a liquid level meter (203) coupled to the ink reservoir (105) for detecting a head pressure difference.

10 8. A print head as claimed in claim 7, characterised in that there is provided an ink tank (204) for a supply of ink, and a valve (211) provided between the ink tank (204) and the ink reservoir (105), the valve (211) being controlled in response to variations
15 in the head pressure difference.

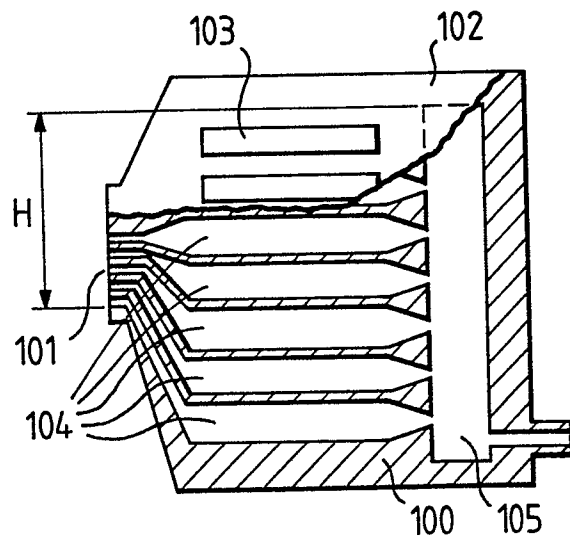
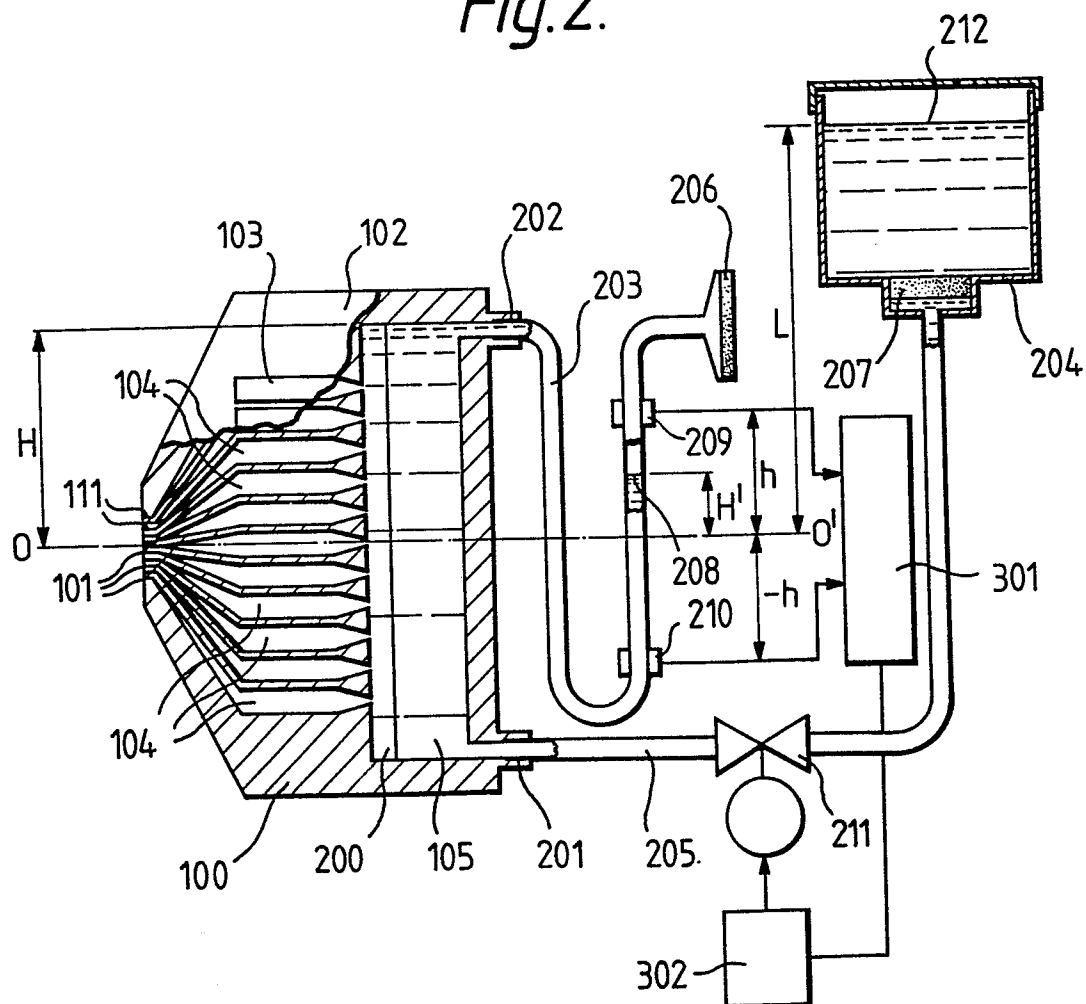
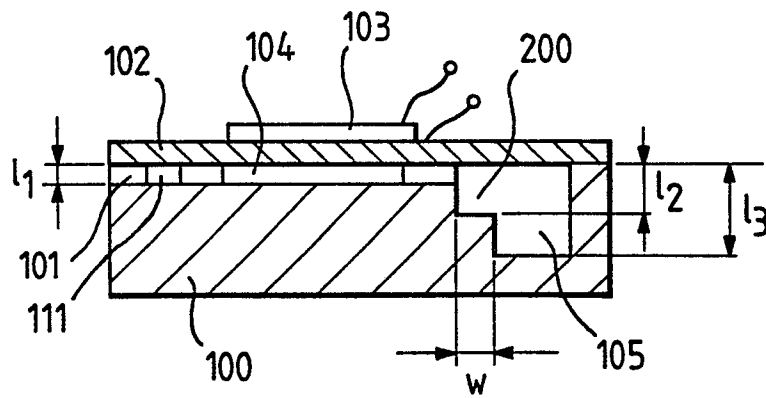
Fig.1.*Fig.2.*

Fig.3.*Fig.4.*