New Developments in Epson's Inkjet Head Technology

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Abstract

Today, color inkjet printers are being used extensively in both offices and homes. Inkjet printers have many advantages including print quality, low cost, and a small footprint. Epson has continued to develop improved printheads. This paper describes new technology that doubles the nozzle count and firing frequency, while halving ink droplet size with respect to previously developed heads.

In general, the types of piezo elements for printheads may be classified according to their oscillation mode: longitudinal or flexural. Heads of the latter type are used in low-cost printers. Although heads of the former type have been configured with multi-layer piezo elements, only heads of the latter type with a single layer have appeared in commercial products.

Our new head incorporates a double layer of piezo elements that use the flexural oscillation mode. We reduced the size and optimized the geometry of the pressure chamber in order to obtain a high natural firing frequency. Furthermore, by completely covering the signal supplying electrodes with the piezo elements, the activating reliability and durability were enhanced.

We have launched products such as the Stylus Photo RX500 and CX4600, Stylus C66, and PictureMate with this new improved head. Further development and optimization are ongoing.

Introduction

In recent years, printers are required to output speedily not only sharp text but also high quality photos. Compared to other types of printers, color inkjet printers have advantages, including print quality, low cost, and a small footprint. For these reasons color printers are being used extensively in both offices and homes. Inkjet printers in the consumer market can be divided into two groups based on their ink jetting methods, Mach-jet or Bubble-jet. Epson's inkjet printers belong to the first group and have piezoelectric actuators in the printers to eject the ink droplets.

Piezoelectric actuators are formed by sandwiching together piezoelectric layers and electrodes. Piezoelectric elements can be made, for example, by compressing and baking metal oxide powder (e.g. $BaTiO_3$, $PbZrO_3$, $PbTiO_3$). When electric driving signals are supplied to the electrodes, the actuator deforms according to the drive signals. This deformation is used to change the volume of a pressure chamber and eject ink droplets out of an orifice in the pressure chamber.

Piezoelectric actuators for printheads may be classified according to their oscillation mode: longitudinal or flexural. A longitudinal oscillation actuator is usually columnar. One end is fixed to a firm base, and the other is connected to a flexible wall of a pressure chamber. When a drive signal is supplied to the electrodes, the actuator extends or contracts in its longitudinal direction. Longitudinal oscillation actuators provide powerful vibrations. This type of actuator may be manufactured for printheads that are suitable for high-density printing. On the other hand, flexural oscillation actuators have the construction of a narrow chip. These actuators are formed on a flexible wall of a pressure chamber. When a drive signal is supplied to the electrodes, the area of the piezo element contracts, causing the flexible wall to deform toward the center of the pressure chamber. Flexural oscillation actuators can be manufactured by a relatively easy process (printing and baking piezoelectric paste on a metal chip with previously formed pressure chambers). Printheads of this type are suitable for low-cost printers. Although heads having longitudinal oscillation actuators have been configured with multi-layer piezo elements, only heads with single-layer flexural oscillation actuators have appeared in commercial products.

There are questions about whether a flexural oscillation type printhead with multi-layer piezo elements is better than a printhead with only a single piezo layer, and about what is the optimal structure for heads with multi-layer piezo elements.

Inkjet Printhead Structure

Figure 1 shows the structure of a flexural oscillation type printhead. Ink is supplied from an ink container through a reservoir and supply channel into a pressure chamber. When the volume of the pressure chamber contracts, pressure in the pressure chamber increases. The increased pressure ejects ink droplets from the nozzle connected to the pressure chamber. Such a printhead consists of two main parts: an actuator unit and a nozzle unit. The actuator unit is manufactured by the following process. First, zirconium green sheets for a vibration plate, pressure chamber plate and connection plate are shaped. Next, they are bonded together as a set, and then baked. After that, pastes containing electric conductive materials and pastes containing piezoelectric materials are successively printed on the vibration plate to form electrodes and piezo elements, respectively. Finally, the actuator unit is finished by baking it again. The nozzle unit is made by shaping a nozzle plate, reservoir plate and supply channel plate, and then bonding the plates together with an adhesive.

Dynamics of the Ink Flow

Ink flow is driven by the motion of the vibration plate. The motion of the vibration plate depends, in turn, on the driving pulses supplied to the actuator. To understand the dynamics of the whole system, we use an acoustic model in which the interaction of the ink, the vibration plate and the driving pulse are taken into consideration.

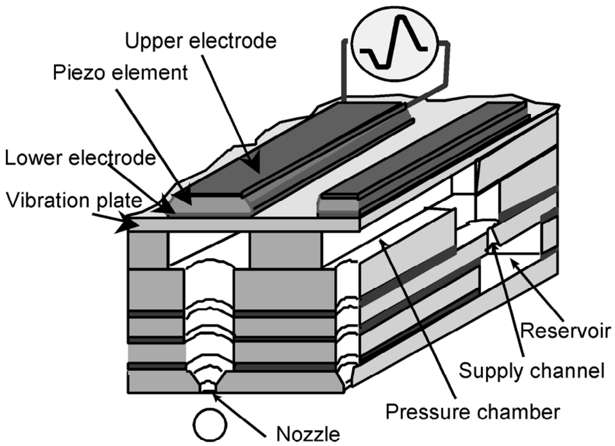


Figure 1. Inkjet head structure

Ink flow may be described by a model taking volume velocity and pressure as independent variables. The motion of the vibration plate is linked to the flow through pressure in the ink. Elasticity of the vibration plate and its deformation may be expressed in terms of a compliance and a charge of the compliance. Thus the supply of pressure to the ink flow can be used to express the supply of the driving pulse. An equivalent circuit model can be used to represent the acoustic model. Model 1 shows the equivalent circuit model that describes the whole system. In the circuit model, current is equivalent to the volume velocity of the ink flow, and voltage is equivalent to the pressure. As stated above, the driving pulse has the same form as pressure in the circuit model. *P_I/C* expresses the negative pressure generated by an ink cartridge. *Cnoz* represents the pressure of the meniscus at the nozzle. Strictly speaking, the pressure of the meniscus cannot be described by using a capacitor when the meniscus has a large deformation. A capacitor can only describe the effect of the meniscus near the initial position. An approximation may be given by:

$$Cnoz = \frac{\pi d^4}{48\sigma} \tag{1}$$

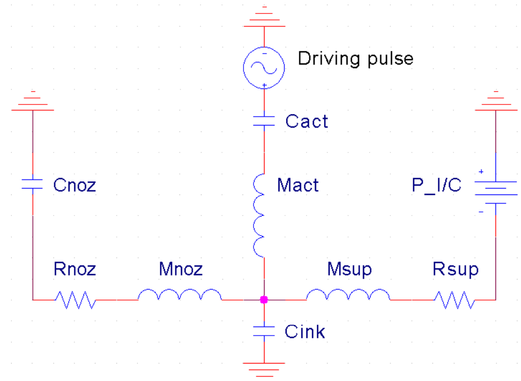
where d is the diameter of the nozzle, and σ is the surface tension of the ink. The other constants C, R and M represent compliance, resistance and inertance. The suffixes *noz*, *sup* and *act* indicate nozzle, supply channel and actuator, respectively. For example, supposing the nozzle is cylindrical, *Mnoz* and *Rnoz* may be given by:

$$Mnoz = \frac{4\rho l}{\pi d^2} \tag{2}$$

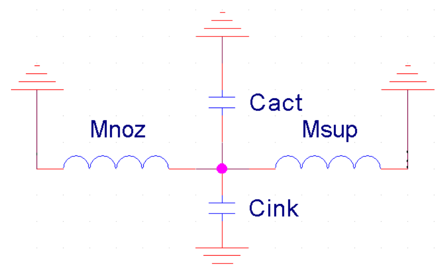
$$Rnoz = \frac{128\mu l}{\pi d^4} \tag{3}$$

where ρ and μ are the density and viscosity of the ink, and l is the length of the nozzle. The behavior of the system can be simulated on a computer. Two important vibration modes can be calculated without doing a computer simulation. A model for the vibration mode of the pressure chamber is shown in Model 2, which is obtained by omitting components with no relation to the mode in Model 1. The vibration period can be calculated as follows:

$$Tc = 2\pi\sqrt{\frac{(Mnoz \times M\sup)(Cact + Cink)}{(Mnoz + M\sup)}} \tag{4}$$



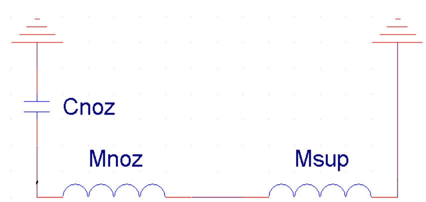
Model 1. Equivalent circuit model



Model 2. Model for vibration mode of pressure chamber

To eject ink droplets at a high frequency, we need to design a printhead that has a short *Tc*. Model 3 shows the equivalent model for the vibration mode of the meniscus. The vibration period *Tm* can be calculated by:

$$Tm = 2\pi\sqrt{(Mnoz + M\sup) \times Cnoz} \tag{5}$$



Model 3. Model for vibration mode of meniscus

If a printhead has a long *Tm*, the ink ejected from the nozzle will not be refilled into the pressure chamber quickly. Such a printhead also cannot be driven at a high frequency. From equations *(1)* and *(2)* we see that using nozzles with small *d* results in short *Tm.* But from equation *(3)* we see the resistance is inversely proportional to the 4th power of d. Large resistance makes the refilling of ink slow, which is also antithetical to high frequency driving.

Now we have the basis on which to discuss the design of a printhead. The displacement *Dy* of the vibration plate at the center of the pressure chamber, which is obtained by supplying a driving pulse to an actuator, is an important factor for a printhead. The displacement together with the area of the vibration plate facing the pressure chamber determine the amount of the contraction of the pressure chamber's volume (*Qcontr*). Although the size of the ink droplets can be controlled by supplying appropriate driving signals, generally a contraction in volume that is larger than the largest ink droplet from a printhead is needed. This volume is needed because the ink droplet equal to nearly half of the volume of contraction jets out of the nozzle, while the ink equal to the remaining volume of contraction returns to the reservoir through the supply channel. The volume of the ink droplet *Qink* can be estimated by:

$$Qink = \frac{M\sup}{(Mnoz + M\sup)} Qcontr \qquad (6)$$

The compliance of the actuator *Cact* is another important point for a printhead. It can be seen from equation *(4)* that to obtain a printhead with a short *Tc* we must use an actuator of small *Cact*. We see now from the point of forming the ink droplet that an actuator having greater displacement *Dy* and smaller compliance *Cact* will be a better actuator. Considering the displacement *Dy* and the compliance *Cact*, an actuator with multi-layer piezo elements theoretically has advantages over an actuator with only a single piezo layer. However, when manufacturing techniques, cost, activating reliability and other design factors are taken into consideration, the question about whether a flexural oscillation type printhead with multi-layer piezo elements is better than a printhead with only single piezo layer still cannot be answered.

Newly Developed Printhead

Figure 2 shows a cross section of the actuator for the newly developed printhead. The lower electrode, lower piezo layer, inner electrode, upper piezo layer and upper electrode are successively laminated on the vibration plate. This actuator generates increased displacement and has reduced compliance compared to the earlier actuator having a single piezo layer. For an actuator with a single piezo layer, the thinner the piezo layer, the greater the displacement. Conversely, however, the thinner the piezo layer, the greater the compliance. The lower and upper electrodes are connected together at an end of the actuator in the length direction, and are grounded.

Figure 3 shows cross sections of the newly developed printhead's pressure chamber and of the previous printhead's pressure chamber. The length of the pressure chamber in the new head is less than half that of the previous head. Ninety nozzles can be formed in an actuator unit chip for the new head. In comparison, only 46 nozzles can be formed in an actuator unit chip of nearly the same size for the previous head. Since the cost of the chip is essentially proportional to its size, the nozzle count is increased from 46 to 90 at virtually no additional cost. The new head's contraction volume is only half that of the previous head. But since the vibration period *Tc* of the pressure chamber is shortened, the driving frequency is raised from 26 kHz to 43 kHz, so a nozzle in the new head ejects the same amount of ink in the same time period as the previous head. At the same time, the size of the nozzle opening is also reduced from 24 μm to 20 μm to avoid slowing down the ink droplet. The smaller nozzle size also helped enable us to reduce the size of the smallest droplet from 4 pl to 2 pl.

Table 1 provides a summary comparison between the new head and the previous head.

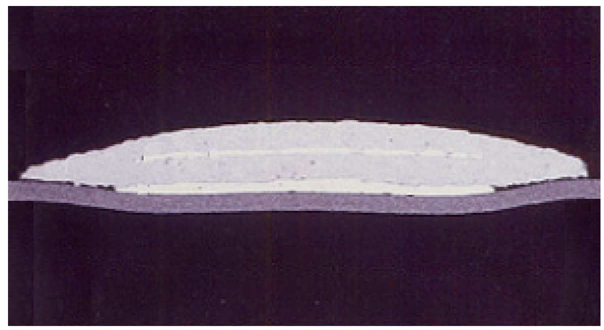


Figure 2. Cross section of new actuator

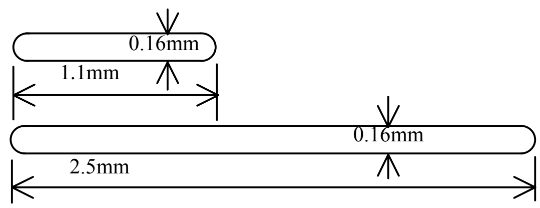


Figure 3. Cross sections of new head's pressure chamber and previous head's pressure chamber

Table 1: Comparison Between New Head and Previous Head

	New head	Previous head
Nozzle count/chip	90 x 2 lines	46 x 2 lines
Driving frequency	43 kHz	26 kHz
Max. ink droplet	7 pl	13 pl
Min. ink droplet	2 pl	4 pl
Nozzle diameter	20 μm	24 μm
Length of pressure chamber	1.1 mm	2.5 mm

To obtain a head having more nozzles, we put several actuator unit chips on a large nozzle unit. Picture 1 shows the 6-color PictureMate photo printer. Three actuator unit chips are installed in this printer.

Picture 1. PictureMate

Conclusion
Our new head incorporates a double layer of piezo elements that use the flexural oscillation mode. We reduced the size and optimized the geometry of the pressure chamber in order to obtain a high natural firing frequency. Furthermore, by completely covering the signal supplying electrodes with the piezo elements, the activating reliability and durability were enhanced.

However, further development and optimization are still needed. The development of a printhead with a higher nozzle density than the new head reported in this paper is one example.

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Author Biography

Junhua Zhang has been working at Seiko Epson Corporation as a researcher since 1991. He received his Ph.D. (1993) from Osaka University, Graduate School of Engineering Science in Control Engineering. His contributions include ink meniscus control for raising the jetting frequency, reducing the ink droplet size and preventing the clogging of nozzle openings. His current interests are in developing new inkjet heads of high performance, improving existing inkjet heads for meeting various printing needs, and applying PZT technology to new products.