New Drive Electronics to Improve Drop Weight Uniformity in Multi-Nozzle Inkjet Heads

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Abstract

It is well known that piezo inkjet technology is capable of depositing a controlled amount of fluid in a specified location very accurately. This technology renders itself well to various deposition applications. We have conducted research to apply inkjet technology to patterning devices. In order to achieve high rates of production throughput, multi-nozzle inkjet heads are needed. One of the issues with multi-nozzle heads is the drop weight variation between channels. The inkjet heads used for this research have 128 piezo-electric elements in line. An analog drive circuit, which creates a trapezoidal waveform, is connected to the common electrode of all elements. The other ends of piezo elements are connected to individual switches. The element discharges on the leading edge of the trapezoid waveform if the other end is grounded by the switch. This causes the element to shrink and pull back the meniscus at the orifice. When it is charged on the trailing edge, the element expands and pushes the meniscus out through the orifice. The discharge level, which influences drop volume, can be controlled by adjusting the duration of the grounding time of the switch. By using this method, it has been shown that the drop weight variations across the 384 nozzles (three heads) can be improved from 25-27ng±20% to 25-27ng±5%.

Introduction

Figure 1 shows the multi-nozzle inkjet head which we provide. The 128 nozzles are created in a line with a nozzle pitch of Np = 1/75 inch. By using stainless steel in the main structure of the inkjet head, along with adopting a laminated PZT layer configuration, the inkjet head has the following favorable properties:

- Applicable to various inks (solid wax, solvent, UV)
- Applicable to high viscosity inks (~10mPa･s ink)
- Applicable to high drive frequencies (20k~30kHz max)
- High durability and longevity (10 billion actuations for each nozzle)

Recently, the application of inkjet heads with regards to the manufacturing process of flat panel displays, has been a major focus. This paper reports the results of an application of an inkjet patterning device in the manufacturing of organic light emitting displays (OLED).

Figure 2 shows a sample structure of an OLED substrate along with the inkjet patterning devices.

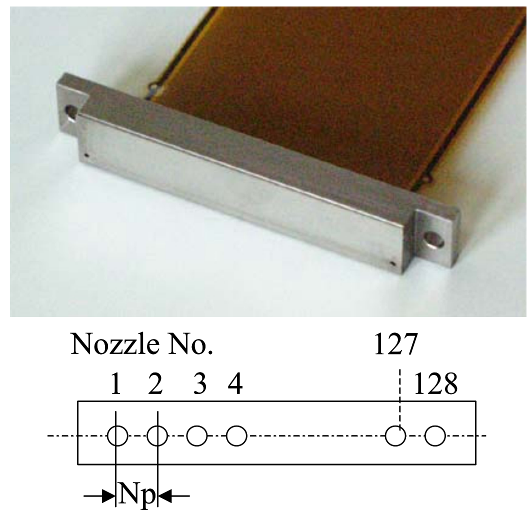


Figure 1. Multi-Nozzle Inkjet Head

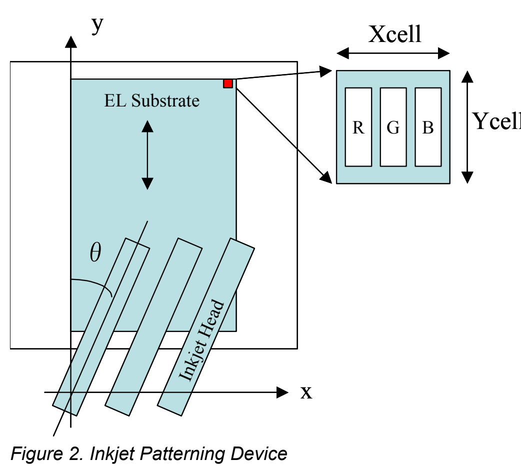


Figure 2. Inkjet Patterning Device

Cells with the pitch Xcell and Ycell (222 µm pitch) are arranged in a grid onto the OLED substrate. There are three separate sub-cells of red, green and blue which are 50µm in width. Light emitting polymer ink and PEDOT ink are dispensed by the inkjet head forming an electrode.

There are three inkjet heads above the OLED substrate which incline at an angle θ to the patterning direction. Thus, they can dispense cells of 384 lines at a time.

sin $\theta = Xcell / Np$

The need for a more precise uniformity of drop weight across the cells is required because luminous variations appear when there is dispersion in the thickness of this light emitting layer.

In this paper, the drop weight specification is 25 - 27ng ±5%, and we must reduce the variations in 1/4 compared with ±20% of the current method. We achieved this with the all nozzle trimming technology.

Structure and Principle

Figure 3 shows the cross section of 128 nozzles in one inkjet head. The PZT can approximate a condenser electrically with the element exhibiting a piezoelectrical effect. A trapezoidal drive voltage wave form is supplied to the common electrode of each PZT and individual electrodes are connected to ground through a transistor switch and diode. The firing of a liquid drop from a nozzle is controlled by the switch signal (SWn).

At first, all PZT's are charged and extended. SWn is ON for the fired nozzles and those individual electrodes are grounded.

The PZT's discharge and shrink and the volume of the chamber is extended during the fall time of the common trapezoidal wave form voltage. A liquid drop fires from nozzle during the rise time of the common voltage. The PZT's are charged and extended, while the volume of the chamber is made smaller. In this paper, the rise and fall times of the common voltage is 2.80µs.

SWn is OFF for non-firing nozzles and those individual electrodes are left floating. There is no change in voltage across the PZT's.

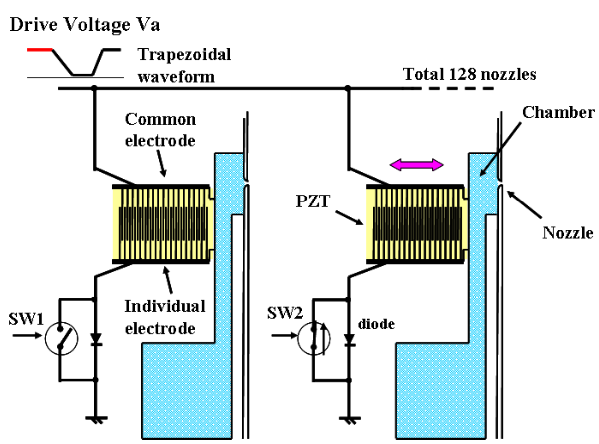


Figure3. Inkjet Structure and Principle

The time width of the switch signal SWn is controlled in our trimming method

Figure 4 shows the structure of the new drive electronics for trimming all nozzles independently.

Every time the OLED substrate moves 6µm, the Timing Generator creates a fire timing signal Tf, which causes the PC to send fire data. The Timing Generator also sends a drive voltage signal Va to the Drive Voltage Generator and a pulse signal of pulse width tn, for each nozzle, to the Switch Pulse Generator. The logical AND of the pulse signal and fire data becomes the switch signal SWn.

Switch pulse data from the PC is stored in the Switch Pulse Generator in advance, and the pulse width tn is output with decided timing in accordance with the switch pulse data.

Our system can accommodate many nozzles because the analog Drive Voltage Generator forms a trapezoidal wave form which is common to all of the nozzles while the individual voltages for each nozzle can be adjusted using digital pulse width modulation techniques.

Figure 5 shows the nozzle trimming principle which adjusts the voltage across the electrodes of the PZT. With the case of a wide pulse width t1 the drop velocity is faster and the drop weight is heavier because the charge voltage across the PZT is larger for the nozzle fire. On the other hand, with a case of a narrow pulse width t2, drop velocity is slower and drop weight is lighter because the charge voltage across the PZT is lower for the nozzle fire.

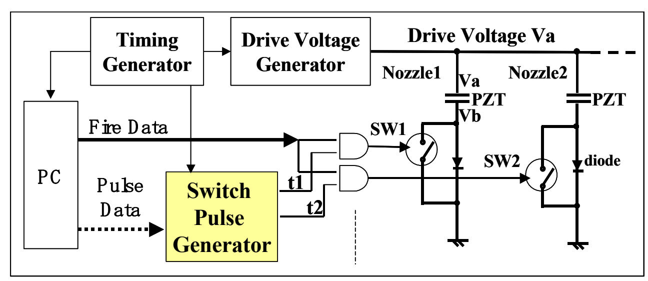


Figure 4. Structure of New Drive Electronics

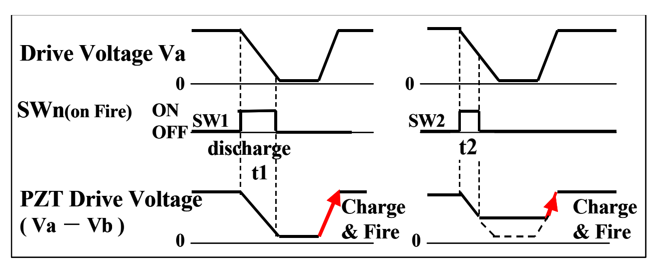
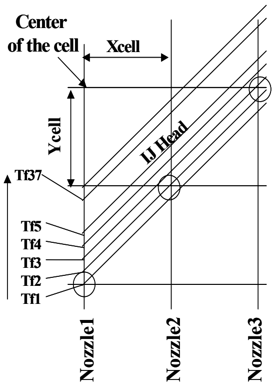


Figure 5. Nozzle Trimming Principle

Figure 6 shows the switch pulse data table stored in the Switch Pulse Generator. Fire timing signal Tf is expressed from Tf1 to Tf37, and these are repeated because timing signal Tf is generated every 6µm and the cell pitch of the Ycell is 222µm. A signal of pulse width tn occurs when the position of each nozzle just meets the center of the cell. The actual timing is decided in accordance with a difference in drop velocity, as explained later.



Switch Pulse Data Table

Fire Timing No.	Nozzle No.							
	1	2	3	4	5	6	......	128
Tf1	t1							
Tf2		t2						t128
Tf3			t3					
Tf4				t4				
⋮					t5	t6		t128
Tf37								

Figure 6. Fire Timing & Switch Pulse Data Table

Results

Figure 7 shows the relationship of drop velocity and weight vs. switch pulse width tn for average nozzles. The vertical axis are drop velocity and drop weight while the horizontal axis are the switch pulse width tn. This case is for drops firing continuously at 2KHz.

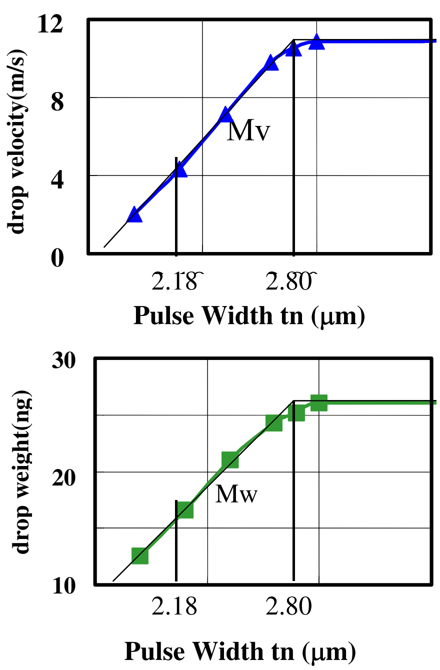


Figure 7. Drop Velocity & Weight vs. Switch Pulse Width Tn For Average Nozzles

A special measuring device is used for the measurement of drop velocity and weight. It takes pictures of a drop flying continuously with an electronic flash and the drop velocity can be measured by the flight distance. It takes several seconds per nozzle to make these measurements and the precision is within 1%. The device also collects 500,000 drops and measures the weight with a precision balance. It takes about 5 minutes per nozzle to make this measurement and the precision is within 1-2%.

Although there is a way to measure the weight of the flying drop from the electronic flash photograph, it can't provide precision with such a simple device.

The drop velocity characteristics exhibits linearity (inclination Mv) between 3 -10m/s ($2.0 < tn < 2.8\mu s$), and it is adjustable in the error of ±0.7m/s. On the other hand, the characteristics of drop weight exhibits linearity (inclination Mm) c between 13 - 27ng ($2.0 < tn < 2.8\mu s$), and it is adjustable in the error of ±0.9ng.

For the faster and slower nozzles, the inclination Mv and Mm are in the same aforementioned area.

Figure 8 shows the relationship between drop velocity and drop weight for non-average nozzles which deviate from the mean.

Since the correlation of both dispersions is high and the inclination is close to Mw/Mv, we know that the drop weight becomes uniform by making the drop velocity uniform using trimming techniques.

So, we developed a new procedure for trimming which makes the drop velocity uniform and the number of nozzles needed to measure the drop weight is kept to a minimum. Thus, a high precision of the landing position and a drastic reduction of the measuring time are both accomplished.

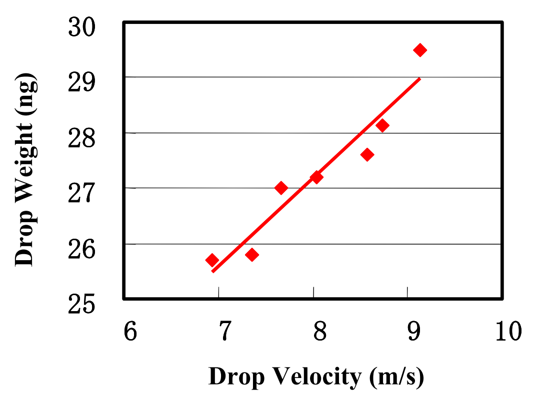


Figure 8. Drop Weight vs. Drop Velocity for non- average nozzles

Procedure of Trimming

1. The switch pulse width tn is set to the longest (2.80μs) width and the drop velocity of all the nozzles are measured.
2. The drop velocity is adjusted to the same goal velocity by trimming. The goal velocity drop should be kept to a minimum.
3. Measure the drop weight of an average nozzle whose amount of velocity adjustment is small and adjust the drive voltage Va to obtain a goal weight.
4. Measure the drop weight of several non-average nozzles whose velocity adjustment is large and adjust not only the

switch pulse width tn, but also the fire timing Tf of the switch pulse data table.

By using this trimming procedure, we not only get the drop weight precision of the velocity goal but also a high precision of the landing position by the adjustment for about one hour.

Figure 9 shows the result of procedures 1 and 2. The horizontal axis denotes the nozzle number, and the vertical axis denotes the drop velocity. The upper data is achieved when all nozzles are driven by the same Va (before correction) at 13m/s± 28%, and the lower data is achieved when their velocity is adjusted by the trimming circuit (after correction) at 8m/s± 5%

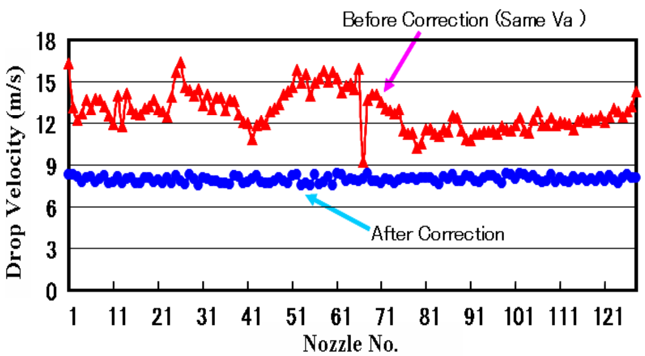


Figure 9. Drop velocity vs. nozzle number before & after velocity correction by trimming.

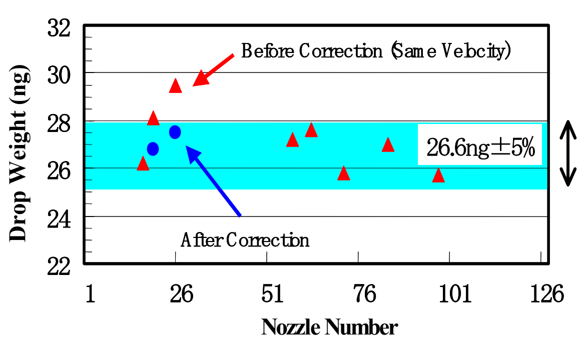


Figure 10. Result of the Trimming Procedure

Figure 10 shows the result of procedures 3 and 4. The horizontal axis denotes the nozzle number, and the vertical axis denotes the drop weight. By using procedure 3, the mean drop weight was found to be 26.6ng. We then measured the drop weight of eight nozzles whose deviation of velocity was large (triangle plot in the figure).

Because we found that two nozzles were out of the target range of 26.6ng ± 5%, we tried to adjust the nozzles by adjusting switch pulse tn using the following equations:

a) Adjustment of Δtn (μs) of Pulse Width tn

Δtn = (26.6 – DropWeight) / Mm

b) Adjustment of Position of a Drop Landing

Since the drop velocity also changes, the fire timing of the switch pulse data table needs to be changed.

$\Delta Dv = \Delta tn\ Mv$

After this trimming process, we then measure the drop weight of all the nozzles. We confirmed that the drop weight of the two nozzles which were out of the goal, changed to the drop weight (circle plot in the figure) in the goal. The drop weight of the other nozzles also stay in the in the goal shown with a band.

Conclusion

We developed a small & simple New Drive Electronics for a multi-nozzle inkjet head. We also developed a trimming procedure which not only achieves precision drop weight, but also reduces the measuring time without lowering the precision of the landing position of the liquid drop. This procedure was applied to a patterning device to an OLED substrate. A drop weight of 26.6ng± 5% could be attained with the 3 head arrangement of 384 nozzles.

Though the trimming time took several hours , the switch pulse data table could be embedded before shipment and therefore adjusted regularly in the end user's factory. Using this new drive electronics enables us to reach a level where inkjet patterning precision in the display production field becomes practical and applying it to broader applications now becomes possible. From now on, we can focus not only on high speed and high precision trimming, but also on the advanced patterning method whose reference value is changed by the external conditions.

References

1. Marlene McDonald, High Precision Jetting and Dispensing Applications Using A Piezoelectric Micropump (IS&T, NIP 19, Springfield, VA, 2003)

Author Biography

Shinya Kobayashi was born in 1958. He graduated from Tokyo Institute of Technology, Japan, in 1983 and received M. in control engineering. He joined Hitachi, Ltd. then joined Ricoh Printing Systems, Ltd. in 2004. He worked in the Research & Development Center for printing systems and controls.