1pL Inkjet Head and G8.5 Equipment Development for 350ppi OLED Display Panels

Hidehiro Yoshida, Shuhei Nakatani, Takashi Inoue,
Yukiya Usui, Futoshi Ohtsuka
Panasonic Production Engineering Corporation, Osaka, Japan

Abstract

This paper reports on the development of 1pL inkjet head and G8.5 equipment for 350ppi display panels. Firstly, we have derived the margin of 350ppi pixels. Then we allocate margins to each key mechanical component and developed the 1pL inkjet printheads with 1.0pL ±2.4% volume variation and ±1.35μm landing position repeatability.

Author Keywords

350ppi margin; 1pL inkjet head; G8.5 stage; G8.5 alignment system; Color mixing detection

1. Introduction

OLED and QLED (Quantum dot light emitting diode) displays require higher and higher resolution when the panel size is medium and small [1,2,3]. At SID 2024, Panasonic reported on the technology for printing G8.5 220ppi OLED panels by inkjet [4,5]. And describes stage moving accuracy and glass alignment accuracy shown in Table 1. This year's report described technologies for printing G8.5 350ppi OLED panels with even higher resolution using inkjet printing.

Firstly, the droplet volume and drop landing accuracy required to print with a resolution of 350ppi were examined. The results of the study were shown in Fig.1. The left-hand side is for 220ppi and the right-hand side is for 350ppi. Previous work has shown that if the center of gravity of the droplet does not exceed the edge of the bank, the droplet will be fallen into the targeted cell. Taking this into account, the required droplet volume and landing accuracy were calculated. We therefore set our development target at a droplet volume of 1pL and a landing accuracy of 5.8 μm.

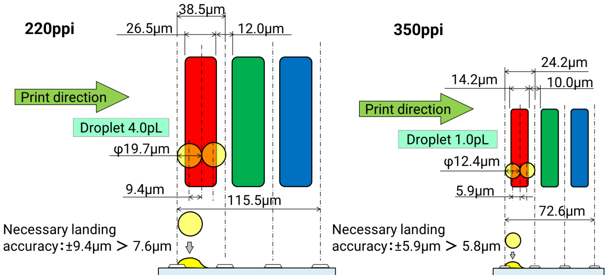

Figure 1. Required droplet volume and landing accuracy

Table 1. The target of each factor for 220ppi and 350ppi

Items				Error 220ppi		Error 350ppi
	Droplet volume			4pL		1pL
Accuracy	Droplet position error	Caused by droplet flight angle	2.5μm	3.0μm		3.0μm
		Caused by droplet velocity variation	0.5μm			
	Stage moving accuracy			1.0μm		0.6μm
	Glass alignment accuracy			0.3μm		0.3μm
	Positional deviation of the suction table			0.4μm	⇒	0.1μm
	Magnification correction error for glass substrate			—		0.3μm
	Detection accuracy of landing position			—		0.1μm
	Others			—		—
	Total drop landing accuracy			7.6μm		5.8μm

Panasonic demonstrated moving accuracy 0.3μm which is less than 0.6μm, and glass alignment accuracy 0.3μm which is equal to 0.3μm at SID 2024. So, we need to develop other factors for printing to a resolution of 350ppi.

The following section described the approach to achieve a landing accuracy of 5.8 μm, as opposed to the 7.6μm required at 220ppi. The main problems at a 7.6μm landing accuracy are shown in Fig.2 and Fig.3. Fig.2 showed the position drift of the substrate alignment camera and inkjet head due to thermal deformation of the gantry over time; Fig.3 showed the misalignment of the substrate alignment mechanism.

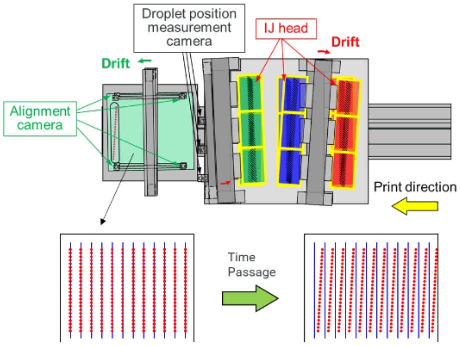

Figure 2. Changes in printing position over time

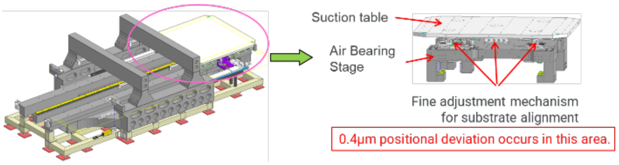

Figure 3. Positional shift when the stage was run out

Based on the target accuracy, we report the 1pL inkjet head development, then we report the G8.5 glass alignment system. And then developed G8.5 stage compensation system.

2. 1pL Inkjet head development

The volume ejected from the nozzles of the inkjet head is determined by the relationship in equation (1).

$$V = ((S \times v) \times T) \times \alpha + \beta \tag{1}$$

V: droplet volume S: nozzle cross section v : jetting velocity
T : resonance period α, β : coefficient

From this equation, the droplet volume is proportional to the nozzle cross section, resonance period and jetting velocity. As jetting velocity is a process condition, there are two head design strategies to reduce droplet volume. One is to get smaller the nozzle diameter. The other is to reduce the volume of the pressure chamber to shorten the resonance period of the ink. However, if

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the nozzle diameter is got smaller, the nozzle tends to clog by ink. Furthermore, it becomes more difficult to process the nozzle, and it is difficult to process the nozzle holes with high precision. High-precision nozzle machining is an important factor, as the landing accuracy is decreased if the nozzle shape varies. Therefore, as a head design to realize small droplet ejection, it is desirable to realize small droplet ejection by reducing the volume of the pressure chamber.

To increase productivity in inkjet printing, it is necessary to increase the jetting frequency and the number of jetting droplets per unit time. To achieve high-frequency jetting, the vibrations generated during jetting need to be reduced within a short period of time. This is because inkjet jetting uses the resonance phenomenon of vibration waves to eject, and if residual vibrations remain, proper resonance cannot occur. However, if the volume of the pressure chamber is small, the effect of residual vibration is relatively large, so an inkjet head structure design that suppresses residual vibration is necessary.

We have increased the fluid resistance in the flow paths (orifices) leading to adjacent nozzles in the inkjet head flow paths to suppress residual vibration (Fig.4).

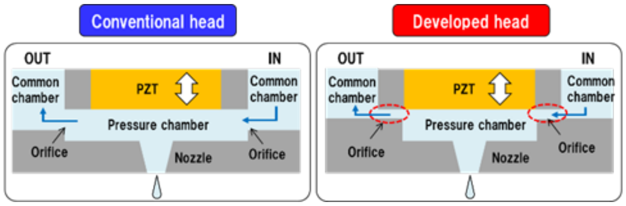


Figure 4. Schematic diagrams of inkjet head

Specifically, the orifice was made narrower and longer to increase the flow resistance. This made it difficult for the vibration waves generated for ejection to return after leaving the pressure chamber, thus reducing residual vibration.

A comparison of residual vibration was carried out using a conventional head and a developed head. As the residual vibration inside the nozzle was invisible, the residual vibration was measured by measuring the time variation of the meniscus area of the ink ejected out of the nozzle (Fig. 5).

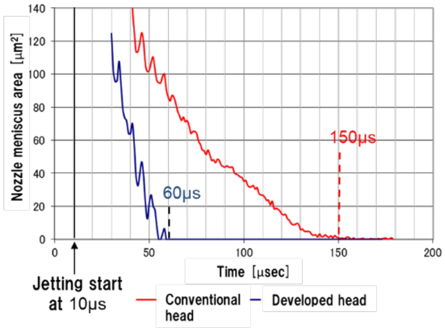


Figure 5. Meniscus vibration with conventional and developed inkjet head

It was found that with the conventional head, it took 150 μsec for the residual vibration to subside. On the other hand, with the developed head, it was found that the residual vibration subsided in 60 μsec. The start of jetting is 10 μsec, meaning that the conventional head can only eject at a cycle of 140 μsec or more. In other words, it can only eject at frequencies below 7 kHz. On the other hand, the developed head can eject with a 50 μsec cycle, meaning that the frequency at which it can eject is 20 kHz, which means that the number of jetting droplets per unit time can be increased by a factor of about three, thereby improving productivity.

Next, the jetting characteristics were evaluated using OLED ink. By the DPN (Drive per Nozzle) function, which adjusts the jetting voltage for each nozzle, a droplet volume of 1.0pL± 2.4% could be ejected (Fig. 6).

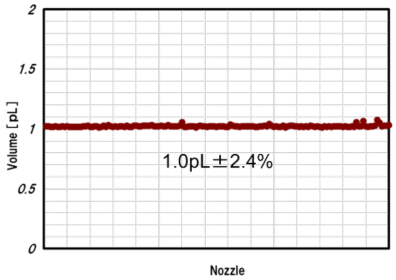


Figure 6. Jetting volume with developed inkjet head

Next, the evaluation of jetting velocity repeatability and landing position repeatability was carried out at two jetting frequencies (Fig. 7), and it was found that at frequencies of 1 kHz and 20 kHz, the velocity repeatability was less than ±0.12 m/s and the landing position repeatability was less than ±1.0 μm. When the stage speed was 150 mm/sec, the ±0.12 m/s velocity repeatability corresponded to ±0.35 μm in landing position repeatability, satisfying the error analysis of less than ±2.5 μm in drop landing repeatability and ±0.5 μm in velocity repeatability.

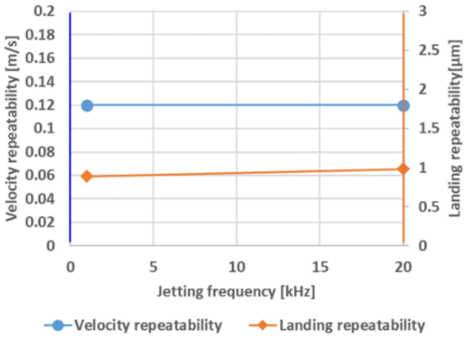


Figure 7. Jetting accuracy with developed inkjet head

3. G8.5 stage alignment system

The developed printing machine is designed to drop ink while running a stage with a glass substrate under an inkjet head mounted on a gantry. The alignment of the glass substrate and the printing position was achieved by measuring the alignment marks on the four corners of the glass substrate with an alignment camera mounted on the gantry and fine-adjusting the alignment fine-adjustment mechanism between the air slider and the suction table based on the measurement results.

In the report on the SID 2024, a function that compensates for misalignment by calibrating the thermal expansion and contraction of the linear scale used to drive and control the stage with a laser length measuring instrument was described. That function eliminated misalignment due to expansion and contraction of the linear scale beyond 10 μm. However, as described above, both the position of the inkjet head mounted on the gantry and the position of the alignment camera can be misaligned by 1-2 µm due to thermal distortion of the gantry after several hours.

In addition, in the above-mentioned fine movement mechanism for alignment, a misalignment of about 0.4µm occurred when the stage was run out after alignment. Furthermore, there is expansion and contraction of the panel pattern formed on the glass substrate itself, and each of these misalignment factors must be suppressed in order to achieve a landing accuracy of 5.8µm. For this reason, countermeasures against suction table misalignment, detection and correction of misalignment of the landing position, and correction of substrate expansion and contraction have been carried out. The target error values after each of these measures were set as shown in Table.1.

3-1 Position movement during stage movement

The suction table is supported by the alignment fine movement mechanism on the slider as shown in Fig.3 and can be moved slightly in relation to the slider. The arrangement of the fine movement mechanism is shown in Fig.8.

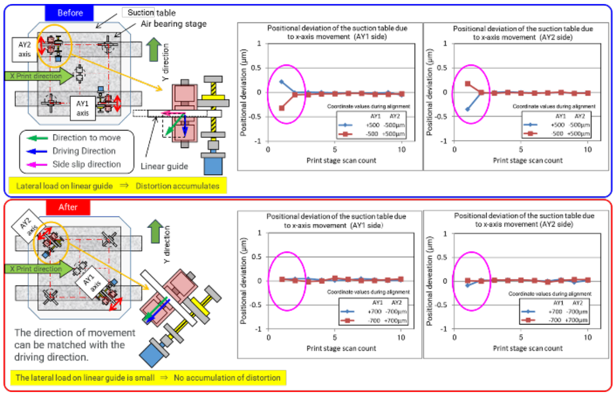


Figure 8. Fine adjustment mechanism for alignment

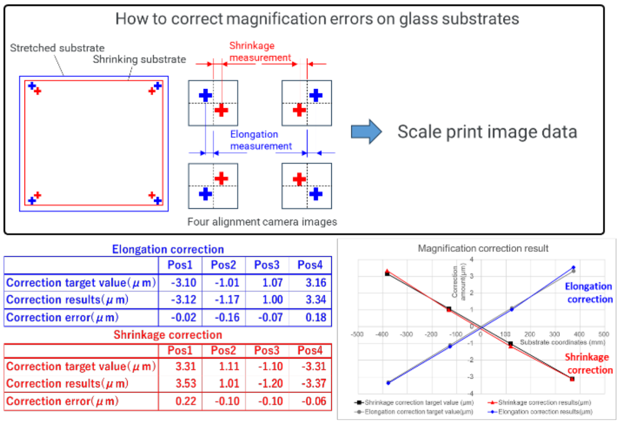
The drive unit consists of a ball screw, motor and linear guide, on which are mounted orthogonal free linear guides. The two drive units are arranged in diagonal positions under the table, with two stacks of orthogonal free linear guides on different diagonals, and a single free linear guide sliding in the Y direction in the center.

Before the countermeasure, the sliding linear guides were arranged in the X and Y directions as shown above in Fig.8. When rotating θ, the free linear guide had to slide the same amount as the drive shaft, and at that time the linear guide of the drive shaft was also deformed by the lateral load, When the stage was moved after the θ-rotation was completed, the deformation was released, causing a misalignment of about 0.4µm.

As a countermeasure, as shown in the lower part of Fig.8, all the constituent units were rotated 45° and placed. In this way, the amount of slippage of the free linear guide during the θ rotation could be significantly reduced and the associated deformation could also be reduced. However, for movement in the Y direction, the drive axes of the two fine adjustment mechanisms must be moved in the same direction and the print stage (X direction) must also be moved. This measure has reduced misalignment to less than 0.1µm even when the stage is moved immediately after fine movement by the alignment.

3-2 Expansion and contraction compensation

The glass substrates used in the production of OLEDs have different expansion and contraction rates on each leaf due to thermal effects during the production process.



Elongation correction

	Pos1	Pos2	Pos3	Pos4
Correction target value(μm)	-3.10	-1.01	1.07	3.16
Correction results(μm)	-3.12	-1.17	1.00	3.34
Correction error(μm)	-0.02	-0.16	-0.07	0.18

Shrinkage correction

	Pos1	Pos2	Pos3	Pos4
Correction target value(μm)	3.31	1.11	-1.10	-3.31
Correction results(μm)	3.53	1.01	-1.20	-3.37
Correction error(μm)	0.22	-0.10	-0.10	-0.06

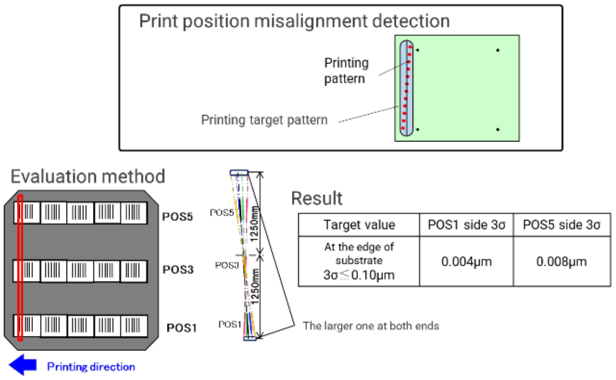
Correction error : 0.22µm < Correction error target : 0.3µm

Figure 9. Substrate magnification correction

Fig.9 showed the method used to compensate for the discrepancy between the panel pattern and the printed position due to this difference in expansion and contraction. As shown in Fig.9, during a substrate alignment, the alignment camera recognizes the alignment marks at the four corners of the substrate and determines the expansion and contraction ratio of the substrate based on the recognized positions, which is used to expand and contract the print data to align the printing position with the panel pattern in the glass substrate. As shown in Fig.9, even with a magnification error of more than 3 µm in the glass substrate, it was possible to align to the target correction error of 0.3µm or less.

3-3 Printing position misalignment detection and correction

As mentioned above, during the passage of several hours, the printing position on the glass substrate is displaced due to thermal deformation of the gantry.



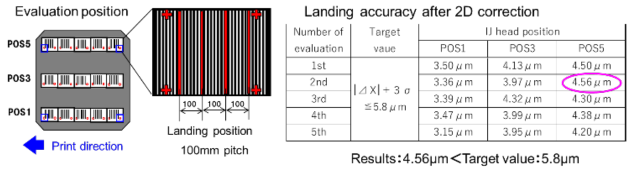
Target value	POS1 side 3σ	POS5 side 3σ
At the edge of substrate 3σ≦0.10µm	0.004µm	0.008µm

Figure 10. Printing position misalignment detection and correction

Therefore, as shown in Fig.10, we have provided a printing target pattern of a few milli meters in width at the edge of the substrate to be printed, printed on the pattern and installed a detection function to measure the drop position.

In the evaluation, the pattern of landing droplet was inspected five times, and the detection accuracy was determined by the maximum deviation of the approximate line. The target detection accuracy of 0.1µm was achieved.

The results of this measurement are used to detect translational and rotational deviations in the print position and to correct the print position.



Landing accuracy after 2D correction

Number of evaluation	Target vaue	IJ head position		
		POS1	POS3	POS5
1st	|⊿X|+3σ ≦5.8μm	3.50μm	4.13μm	4.50μm
2nd		3.36μm	3.97μm	4.56μm
3rd		3.39μm	4.32μm	4.30μm
4th		3.47μm	3.99μm	4.38μm
5th		3.15μm	3.95μm	4.20μm

Results:4.56μm<Target value:5.8μm

Figure 11. G8.5 printing accuracy results for 350ppi

As a result of the above efforts, an accuracy of 4.6 μm was achieved on the entire surface of the substrate, exceeding the target accuracy of 5.8 μm. Fig. 11 showed the results.

4. Color mixing detection system

In G8.5 glass size panel printing by the inkjet printing process, the number of nozzles used in a 1200 dpi inkjet head is more than 100,000. Even with the introduction of the high-precision support for the equipment described above, the ink ejection from the nozzles may suddenly deteriorate due to particle adhesion or changes in the nozzle lip during continuous production, causing color mixing in the production panel.

Therefore, a system is needed to immediately detect this color mixing in production by the printing process, identify the abnormal nozzles, stop them and continue production.

We have built an inspection system for printing equipment that enables the entire surface of the substrate to be imaged immediately after printing. The system was equipped with multiple line cameras, and the lighting arrangement was designed to effectively reveal the wetting spread shape of the printed droplets on the glass surface and the color mixing state, enabling the color mixing to be detected as shown in Fig. 12.

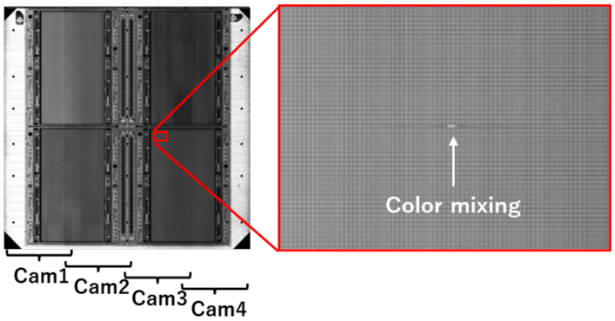


Figure 12. Results of color mixing inspection

This detection system extracts candidate color-mixing nozzles from the coordinates in the image. Based on the results of this color-mixing nozzle candidate and the results of the onset observation carried out on a sheet-fed basis during production, the system identifies the color-mixing nozzles and realizes a high probability of stopping color-mixing nozzles.

Furthermore, we are using this color mixing inspection system to determine the color mixing margin in panel printing production: as shown in Fig.13, we intentionally offset the landing position of the last droplet to be printed in R, G and B, and verify how much the print position is shifted to determine if color mixing occurs. This is used as an indicator of yield stability in production.

These mechanisms and initiatives have enabled highly accurate and stable production using the printing method.

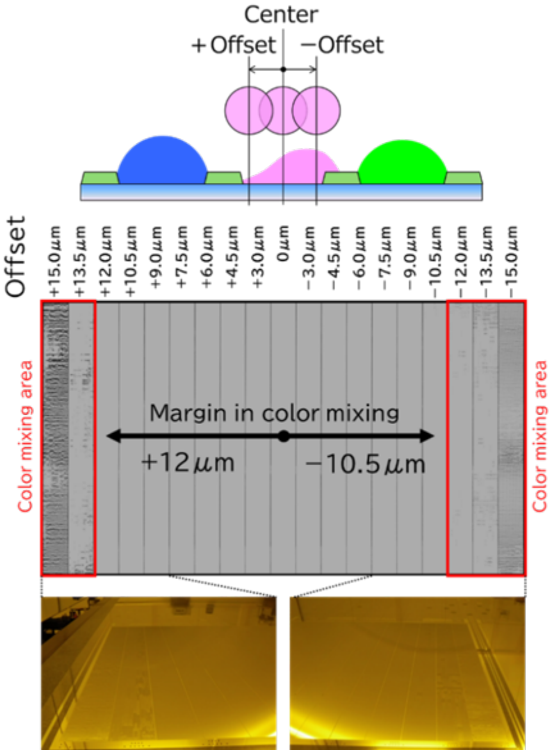


Figure 13. Color mixing margin of 32inch panel

5. Conclusion

By combining 1pL inkjet head technology and precise G8.5 printing equipment technology, we have verified a landing drop accuracy of ±4.6μm in the G8.5 stage area. This enables a wide printing margin with respect to color mixing and is expected to realize stable OLED mass production using G8.5 glass substrates.

6. References

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