Test Pattern and Drop Tracing for Nozzle Healthy Diagnostic

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Abstract

The Rayleigh instability dominates the behavior during the ink drop from jetting to forming. This paper developed a drop tracing methodology for observation the printing quality, identified the drop tail and its break-off period, satellite drop creation, drop volume variation, and jetting speed. After standard recovery cleaning process (spitting, suction, wiping, priming, etc.), the drop landing presentation and its remedy were characterized by a group of test patterns, and furthermore, to be analyzed the failure mode of the nozzles. The measurement method integrated the test pattern design, analysis algorithm and stroboscope scheme, it could automatically trace the historical changes of nozzles and the operation deterioration early warning is possible. Compare with some traditional inspection methods, like off-line auto optical inspection, high speed image capture, continuous tape-rolling dot analysis etc., this method can real-time operate and detect nozzle failure, help the operator revise processing procedure on-line.

Introduction

The nozzle health of print heads is closely relative to the printing quality. Many nozzle health measurement and correction methods have been proposed to maintain the printing quality in the inkjet printers [1, 2, 3]. The major measurement methods include printing a test pattern, dot analysis, stroboscope, optical drop detector, and electrostatic drop detector, etc. The nozzle recovery functions (spitting, suction, wiping, priming, etc.) are performed on a routine basis or after the number of the detected failing nozzles is larger than a given value. However, the recovery functions are generally performed in a predetermined sequence based on the experiences from the research and development phase, which is improper for some nozzle failure modes. The unnecessary or inappropriate recovery procedures can get wear in the nozzle plate and a waste of ink and time, even additional defects in the print heads.

This paper describes some common failure modes and their corresponding head cleaning method. The measurement methods include test pattern and stroboscope. The failure identification can be based on the current status or the historical data of the nozzles.

Test pattern

A test pattern for failure nozzle detecting is described first, as shown in Figure1, and the goal of test pattern design is making the operator who can recognize the failure nozzle at short time. The test pattern is designed in 250 DPI printing resolution which match up the non-interlace printing setting of DTC/ITRI IJP platform. With one print head using, the IJP platform needs five swaths to complete the test pattern printing. 128 lines for each nozzle are drawn in test pattern for failure nozzle detecting. Each line is printed at first swath region in 250 DPI printing, for example, at first row, 6th row, 11th row, etc. And adding other swaths are for labeling printing. So each line is only printed by one nozzle, it can differentiate the nozzle quality from its neighborhood. The positions of the 128 lines need to be arranged for easily being distinguished. The lines printed by odd nozzles are placed in the middle of the test pattern. The lines printed by even nozzles are separated into three kinds of lines. If the number of the line divided by 8 is 2, the line will be placed 0.4 inch ahead of the odd line. If the number of the line divided by 8 is 6, the line will be placed 0.2 inch rearward of the odd line. The last kind of the lines is also placed in the middle of the pattern, but is longer than the lines printed by the odd nozzles. And there are number labels at the both sides of the pattern corresponding to the lines. The text of label number is formed at all five swaths, and the line is formed at first swath. The printing result can recognize the failure nozzle and simply identify printing quality from the luster and the distance of the line to upper and lower ones.

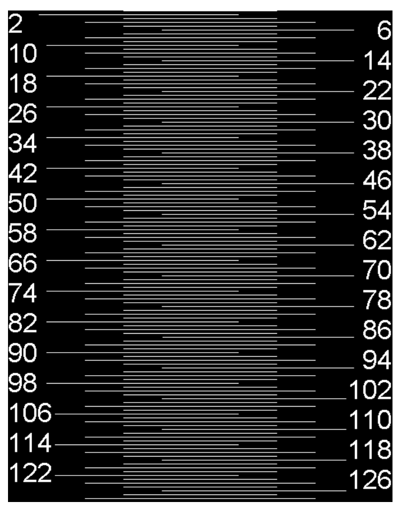


***Figure 1**. Test pattern*

Stroboscope

The strobe method is commonly applied to observe the drop behavior. Figure 2 shows the schematic diagram of the stroboscope of DTC/ITRI IJP platform. The strobe system can measure the drop volume, the number of satellites, drop flying distance, drop length and drop velocity. And using the measured data, we can analyze the drop-to-drop and the nozzle-to-nozzle variations, as shown in Figure 3. Each test printing result is stored in the nozzle database for failure mode diagnostic.

After the print head set-up, the platform performs a procedure, as shown in Figure 4, to clean the print head and then to examine its printing quality. If the test printing result shows that some nozzles are unqualified, the platform will automatically clean the unqualified nozzles. The cleaning procedure will be repeated until all nozzles are qualified or the number of head cleaning reaches the predetermined value. Then the platform selects a succession of qualified nozzles to print. By this means, the printing quality can be ensured.

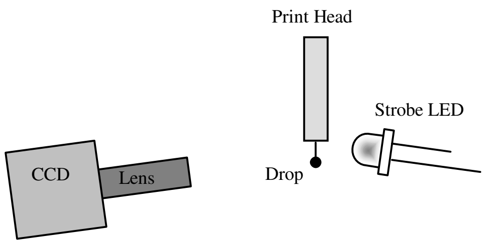


***Figure 2**. Schematic diagram of the stroboscope*

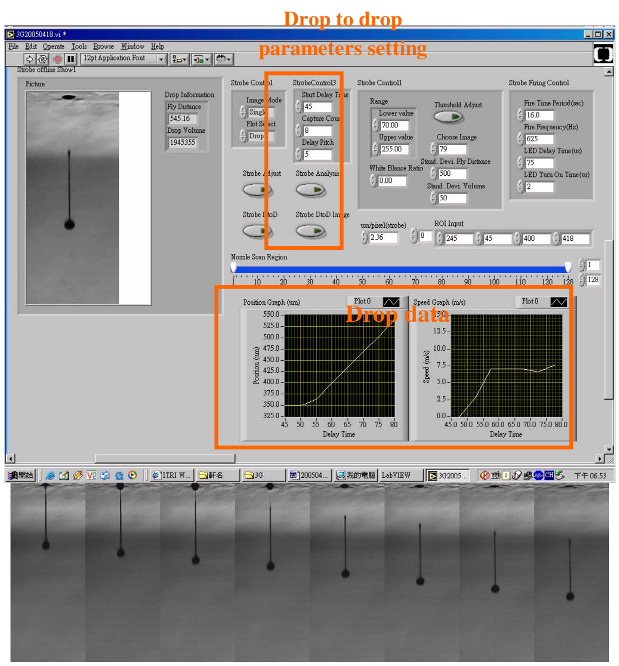


***Figure 3**. Drop to drop analysis function*

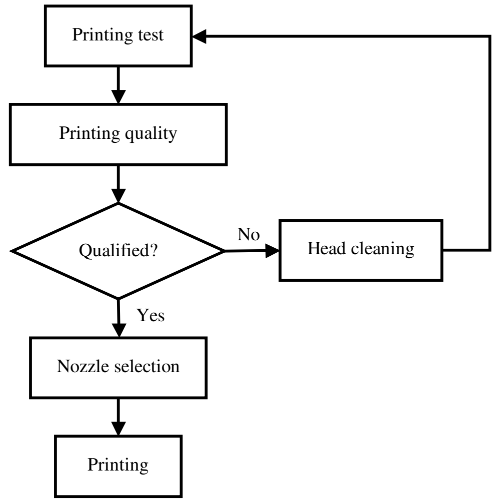


***Figure 4**. Nozzle cleaning and selecting flow*

Failure modes

A Firing stop or jetting quality degradation can result from the following reasons:

(1) Evaporation of volatile inks

For a print head with volatile inks, the concentration and the viscosity of the ink in the nozzles without capping increase gradually during a non-printing time. If the non-printing time is long enough, 3~5 minutes for example, the ink can clog the nozzles.

(2) External particles

If the external particle on the nozzle plate is large enough, it can clog the nozzles. This nozzle contamination can be removed by wiping sequences.

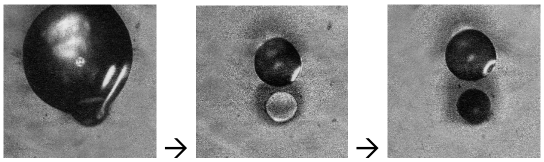
(3) Internal particles

Internal particles trapped by the nozzle or the built-in filter are very hard to remove by the nozzle recovery procedure, such as spitting, suction, wiping and priming.

(4) Air bubbles

Air bubbles sucked into the pumping chamber of print heads can stop drop jetting.

To prevent the problem rising from the ink evaporation, our team has proposed an oscillation method [4]. A smaller driving energy which is less than that of ejection is applied to help the ink circulation in the nozzle by moving the ink forth and back, so as to prevent the ink drying. If the viscosity of the inks in the nozzle exceeds the printable range of that print head, another procedure can be applied, as shown in Figure 5. Due to the high viscosity of the inks in the nozzle, driving the print head can result in puddling. When the volume of the puddling ink reaches an appropriate size, stop driving. Then the ink outside the nozzle can be sucked into the nozzle by the meniscus vacuum of the print head. This process help to mix the high viscosity ink in the nozzle with the lower viscosity ink in the inner channel. Thus ink viscosity in the nozzle is decreased and may reach the printable range. For a thermal bubble print head, the ink accumulated during this process also help to decrease the viscosity of the ink. Depending on the print head and the ink properties, repeating this process for several times can recover the nozzle jetting.



(a) Puddling (b) Retracting (c) Jetting

***Figure 5**. Strobe images from puddling to jetting*

Air bubbles

Air bubbles introduced into the channels or chambers of print heads can disturb the ink fill and the ink jetting and even stop firing. The air bubbles can come from the inside or the outside of print heads. For the first case, the air bubbles are usually produced during initial priming. For the second case, the air bubbles can result from an excess meniscus vacuum which can cause nozzles to inspire air. Pressure purges are commonly used to push air bubbles out the nozzles and transfuse ink into the jetting assembly. Figure 6 shows the strobe images captured before and after pressure purges. The nozzles that can not jet after the initial priming are recovered by an effective pressure purge. If the purge pressure is not large enough, the bubbles will be trapped in the nozzles or the built-in filter of print heads, failing to push the bubbles out the print head.

The nozzle failure resulted from air bubbles can be identified by comparing the test printing data before the purge to that after the purge. If inks are well-filtered and not volatile, the nozzles that which stop firing because of air bubbles can recover after an effective purge.

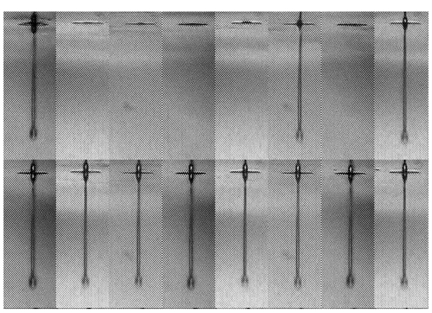
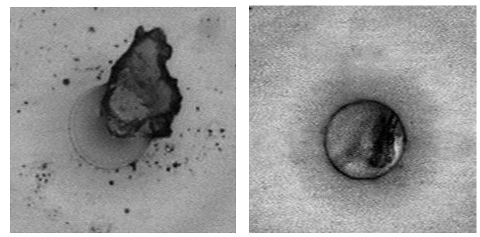


***Figure 6.** Strobe images before (upper) and after (lower) pressure purges*

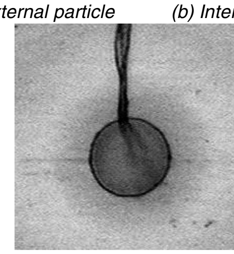
Nozzle contamination

The nozzle contamination could be internal or external, as shown in Figure 7. The internal particles are introduced with the ink and hardly removed by the head cleaning process. If inks are not well-filtered, many particles will be trapped by the nozzles. The external particles come from the outside of the print head and can be removed more easily. The fiber inserted into the nozzle usually results from wiping the nozzle plate with tissues. Every kind of nozzle contamination could degrade the printing quality and even prohibit the drop ejection. The drop ejected from a nozzle with particles usually has obvious deviation and as it lands on the media the satellites near the dot can be observed. Figure 8 shows a dot ejected from the nozzle in Figure 7(a). The main dot is deviated and has a satellite near it.

This kind of nozzle failures can be identified by the printed test pattern. Comparing with adjacent lines, the line printed by the contaminated nozzle is deviated and narrower.



(a) External particle (b) Internal particle



(c) Fiber

***Figure 7**. Nozzle contamination*

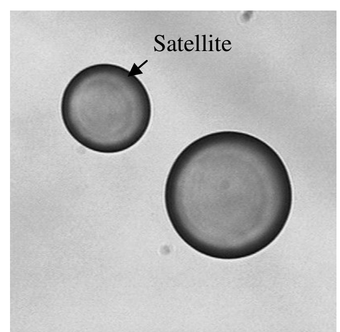


***Figure 8**. A dot ejected from the nozzle in Figure 7(a)*

Aging of the actuator elements

In the print head, the aging of the actuator elements is accompanied by inkjet performance degradation. For a PZT print head, the aging can result from the PZT fatigue which is accelerated by a high driving voltage or a high temperature [5]. For a thermal bubble print head which is fabricated by the semiconductor process, the repeating thermal cycles can result in thin film delamination, as shown in Figure 9. The upper passivation layer is separated from the lower heating resistor, obstructing the heat conduction from the heater to the ink. Thus the thermal bubble on a delaminated heater will be smaller than a normal one, as shown in Figure 10. A smaller thermal bubble produces a smaller driving force which decreases the drop velocity and the drop volume. In Figure 11, the dot size printed on the media decreases as the print head aging.

By monitoring the historical changes of the drop velocity and the drop volume stored in the nozzle database, the print head life can be estimated and an operation deterioration early warning is possible.

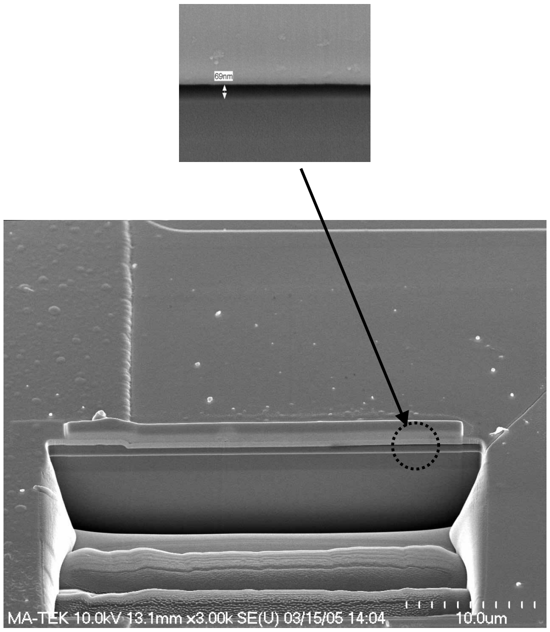


Figure 9. *Thin film delamination of the heater in the thermal bubble print head*

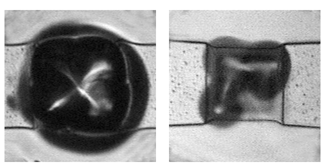


Figure 10. *Comparison of the thermal bubbles in the open pool (Left: normal heater; right: aged heater. Delay time = 5 μs)*

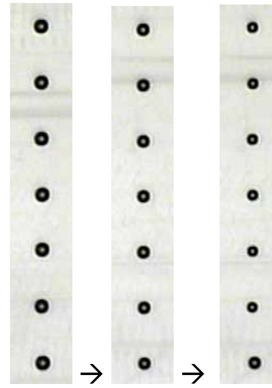


Figure 11. *Dot size decreasing as the aging of print heads*

Conclusion

Common failure modes and their corresponding head cleaning method were described in this paper. Cleaning the print head according to its failure mode can save ink and time and can extend the print head life.

By integrating the printing quality identification and the head cleaning functions, the unqualified nozzles will be excluded and the printing quality can be ensured. In addition, the data of the nozzle history and the related failure mode is very valuable for the improvement of the print system.

References

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Author Biography

Chen-Chu Tsai received his Ph.D. in mechanical engineering from Chiao Tung University in 2004. Since then he has worked in the Display Process Integration Technology Division, Display Technology Center of Industrial Technology Research Institute in Taiwan. His work has focused on the development of ink-jet printing platforms.