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Inkjet jet failures and their detection using piezo self-sensing

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ABSTRACT

As inkjet technology has recently emerged as one of the powerful patterning tools for manufacturing electronic devices, jetting reliability issues have become important. To ensure jetting reliability, jetting monitoring techniques based on piezo self-sensing have been drawn attention to, which detect jet failures due to air bubble entrapment in the printhead. However, the monitoring method based on piezo self-sensing has the capability to detect many other inkjet jet failures. In this study, we investigate the self-sensing signal behaviors in relation to various jet failures other than air bubble entrapment, such as failure of the inkjet head temperature control, abnormal backpressure in the fluidic system, nozzle blockage, etc. To clarify the detectability of various jet failures, we compare self-sensing signals with jet images. From the experimental study, we found that various jet failures can be detected by using the self-sensing signal, and the self-sensing behaviors are different according to the fault causes.

1. Introduction

The application of inkjet technology has broadened from desktop printers, to a manufacturing tool for electronic devices. To ensure productivity and reliability as manufacturing tools, the inkjet jet status needs to be monitored, and jet failures must be identified and fixed immediately. To detect jet failures, the use of piezo self-sensing signals has been proposed [1–5]. A piezo inkjet head uses a piezo actuator to jet ink droplets. On the other hand, the piezo actuator can be used as a sensor, by sensing the force that results from the pressure wave of ink inside the inkjet dispenser. As a practical inkjet monitoring application, the detection of air bubble entrapment in the inkjet head was mainly discussed in most published literature [1–7]. However, few published literatures discuss the self-sensing behaviors in relation to other causes of jet failures. Recently, we have developed an inkjet monitoring system based on piezo self-sensing, to monitor the jetting status of a commercialized multi-nozzle inkjet head [5]. In this study, as an extended work from our previous study, we used the monitoring system to investigate the piezo self-sensing capability of detecting various inkjet failures. The possible causes of jet failures include inkjet head temperature control failure, backpressure control failure, wetting on the nozzle surface, nozzle blockage, etc. To verify the detectability of these jet failures, jet images are acquired for comparison with self-sensing signals. From the experimental results, we found that self-sensing signal behavior was different, according to the causes of jet failures. This can be useful in practice, because schemes for maintenance to correct jet failures can be easily sought, if the causes have been identified.

2. Experiments

Recently, we have developed a low cost and high speed monitoring module, to monitor a multi-nozzle head having 128 nozzles (S-Class, Dimatix, USA) [5]. As an extension of our previous work, we improved the system to use it to monitor a 256 nozzle head (Q-class, Dimatix, USA). Our recent development can be found from the website in Ref. [8]. The detection method is basically the same as our previous work in Ref. [5], and the details will not be discussed further in this study.

Fig. 1 shows a schematic of the experimental setup to investigate the self-sensing behavior in relation to various jet failure causes. Here, to verify the monitoring capability of the self-sensing signal, a drop watcher system based on a strobe light emitting diode (LED) is used to visiualize the jet images.

To determine the jet failures based on the self-sensing signal, reference signals, measured at normal jetting conditions, x_k^r, need to be compared with the monitoring signal, x_k^m. Among other methods for comparing two signals, the cosine value of the signals or variance value has been used in inkjet malfunction detection based on self-sensing signals [4,5].

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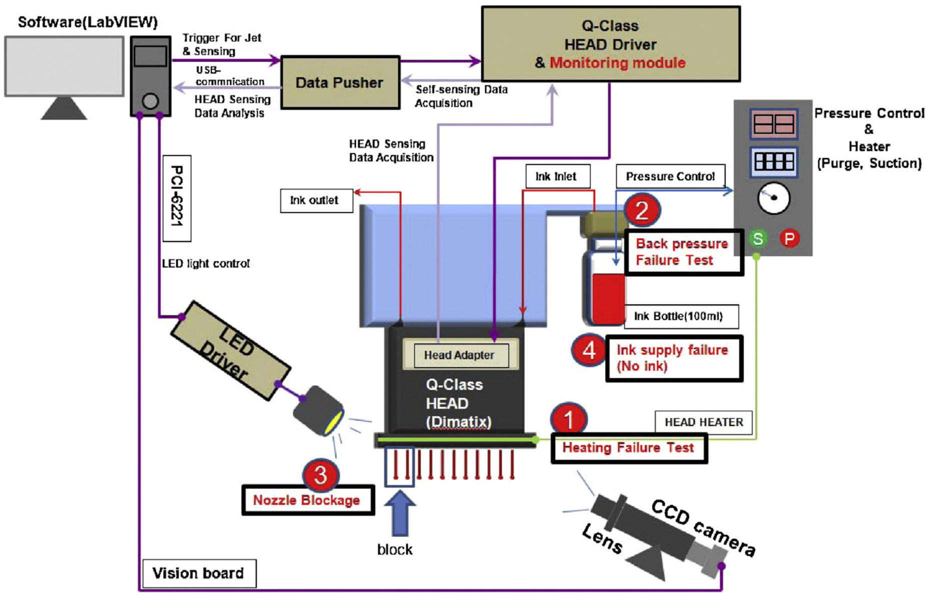

Fig. 1. Schematic of experimental setup.

The value of cosine between the reference and monitoring signals (or vectors), C_k, of nozzle number, k, is defined as [4]

$$C_k = \frac{x_k^r \cdot x_k^m}{|x_k^r||x_k^m|} \tag{1}$$

The cosine value using Eq. (1) mainly detects the phase change of the monitoring signal, with respect to the reference signal. The advantage of using the cosine value is that the value can be normalized, having a maximum value of 1. Here, a cosine value close to 1 means that the jetting status is normal. Robust fault detection can be possible, because it is relatively insentive to measurement noise. However, only critical conditions can be detected, ignoring minor problems, because the value is insensitive to slight signal variation. In some inkjet failure cases, the amplitude of self-sensing signals could mainly be affected with slight, or no phase change. Then, the possible jet failue might not be detected, because the cosine value is close to 1, in spite of signal variation.

On the other hand, the variance value, V_k, has been used for detecting inkjet malfunction based on self-sensing signals [5]. The variance value can be defined as

$$V_k = \sum_{j=1}^{N} \left[x_k^r(j) - x_k^m(j)\right]^2 \tag{2}$$

here, N represent the number of sampled self-sensing data. In this study, V_k is compared to a threshold value, to judge the jetting status [5]. The advange of using Eq. (2) is that slight variation of the self-sensing signal can be effectively detected. Here, the average of self-sensing signals from all jetting nozzles is used as the reference signal, to determine the jetting abnormality of a specific nozzle of interest.

To identify the jet failure causes, more information might be needed, in addition to the variance value using Eq. (2). The possible information includes frequency, phase and amplitude of the self-sensing signal. The software algorithm development required to identify the jet failure causes based on the measured signals is beyond the scope of this work, and needs further study.

2.1. Temperature failure

For jetting fluid, standard inkjet ink (XL-30, Dimatix, USA) was used. For jet consistency, the temperature of head should be controlled, since ink viscosity changes according to the temperature. Fig. 2 shows the viscosity behavior of the ink according to the temperature. Here, the viscosity was measured by use of rheometer (DV-III, Brookfield, USA). The recommended viscosity for the inkjet head (QS-30, Dimatix, USA) is around 8–10 centipoise (cP). To maintain the optimal viscosity for jetting, a heater is placed on the inkjet head, to control the temperature of fluid at 40 °C.

To obtain proper jetting, the proper driving voltage should be used [9]. For this purpose, a simple trapezoidal waveform is used. The rising, falling and dwell time of the waveform were set to 3 μs, and the amplitude of the voltage was set to 75 V, to obtain the jetting speed of 4.7 m/s. Note that the self-sensing signal, as well as the jetting behavior, could be significantly different, according to the driving waveform.

To investigate jet behavior and the self-sensing signal according to the temperature, the setting temperature of the heater on the head was increased from 30 °C to 60 °C. Fig. 3 shows the

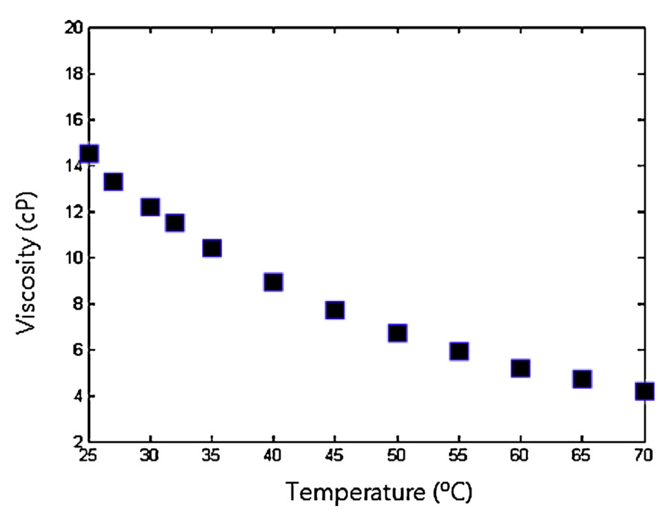

Fig. 2. Viscosity of standard ink according to temperature.