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Controlling Print Height in an Ink Jet Printer

Abstract: This paper describes a control system for maintaining constant print height in an ink jet printer. Following power on and during a periodic off-line correction operation a specially designed sensor detects the position of a test group of electrostatically charged ink drops to obtain print height correction data. Information provided by the same sensor is used to synchronize the application of a unique charge to each drop to be printed.

Introduction

A synchronous electrostatic ink jet printer is sensitive to small temperature variations, primarily because of the resulting changes in ink viscosity. Drop velocity is a function of ink viscosity, and the velocity of the charged drops passing through the deflection plate electrostatic field affects the drop trajectories. In an office environment, temperatures can vary as much as 22°C. Without correction for temperature (and other factors having much less effect), the height of printed characters could change as much as 30 percent.

We selected a method for maintaining constant drop velocity that required development of a sensor to detect the presence and position of charged ink drops. Ink pressure, and thus drop velocity, is regulated by a pump [1] that is controlled by deflection height feedback information from the sensor. (We later decided to use the same sensor to ensure correct synchronization of the drop charging process.)

Sensing the positions of charged ink drops in flight is complicated by several factors. To adequately control print height, drop position had to be sensed to within ± 12.7 μm (± 0.5 mil), yet the charge on each drop is only about 0.5 pC. To avoid contamination by the ink, the sensor could not be closer than about 2.54 mm (100 mils) to the stream of drops. These conditions, combined with the size constraints imposed by the application, led to an approach involving a specially designed, highly sensitive transducer. The sensor, using a 128-drop group to obtain sufficient signal strength and a high input impedance amplifier with input capacitance of 3 to 5 pF, can detect deflection height errors as small ± 7.62 μm (± 0.3 mil).

For pressure correction and charge synchronization, which are accomplished at start-up time and after either each page or an 80-second time interval, the printhead is driven to a stop on the right side of the machine out of line with the paper being printed. Test streams of specially charged drops are deflected past the sensor.

Two distinct groups of test drops are generated by applying two sequences of charging voltage levels to the charge electrode. The first test group is sensed to determine relative height; this information is used to adjust stream velocity via the pump. The second test group is detected to determine charging synchronization; this information is used to control the timing of the pulses supplied to the charge electrode with respect to drop generation.

Here we first describe the sensor and its use in controlling print height, both immediately after start-up and periodically during operation. Finally, we discuss the use of the sensor in maintaining drop charging synchronization.

Charged drop sensor

The deflection of a charged ink drop passing through a parallel plate deflection system is illustrated in Fig. 1. Drop deflection, x_d, is

$$x_d \approx \frac{V_{ce} V_{dp}}{\rho d_j v_j^2},$$

where V_{ce} is charge electrode voltage, V_{dp} is deflection plate voltage, ρ is ink density, d_j is jet diameter, and v_j is jet velocity.

Neither ink density nor jet diameter are much affected by temperature changes (the sum of their influences is only a 2-3 percent change in deflection height). Parameters V_{ce} and V_{dp} are directly proportional to deflection errors. Velocity v_j, the dominant factor, can change as much as 15 percent over the operating temperature range due to viscosity changes. Because v_j is squared in the deflection equation, the corresponding changes in deflection height could reach 30 percent. To obtain our

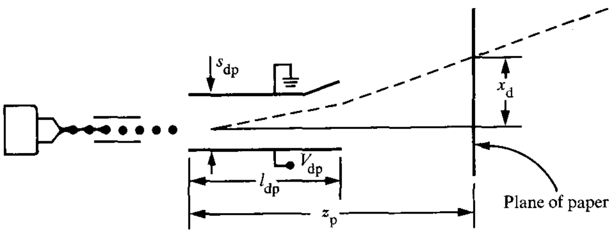
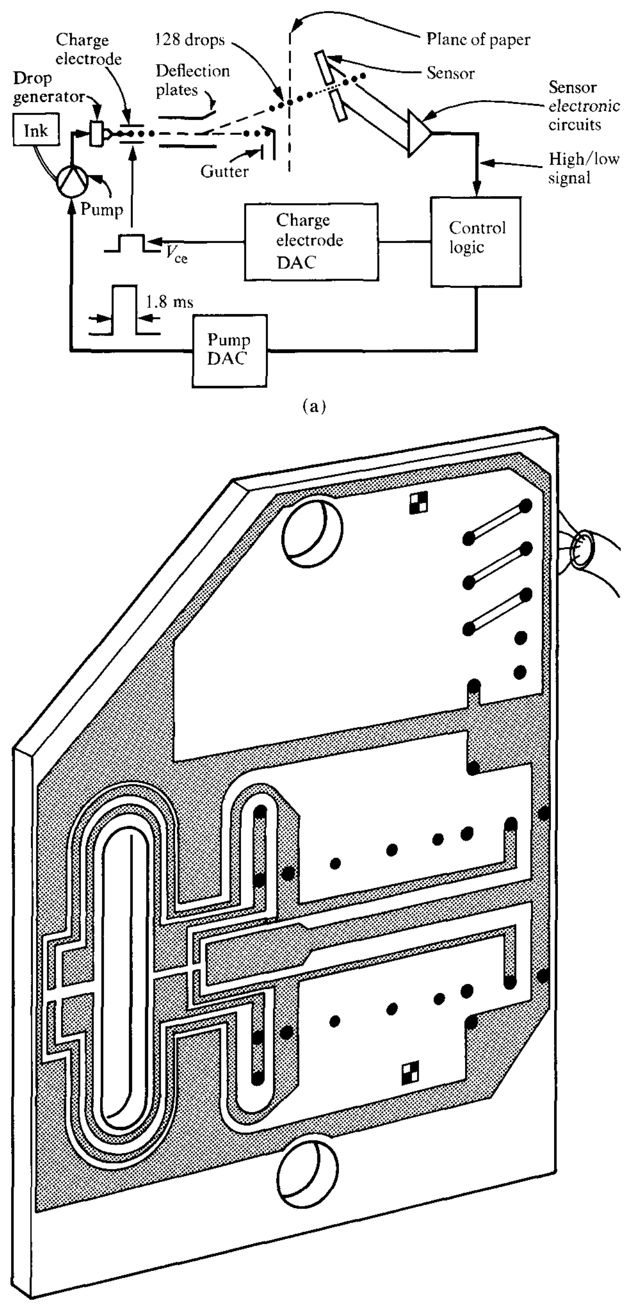


Figure 1 Electrostatic deflection system.



(b)

Figure 2 Closed-loop pressure servo system (a) and charged drop sensor (b).

objective of ±2 percent control of print height we thus chose to measure deflection height and to control it via the most significant parameter, jet velocity.

The sensor shown in Fig. 2 provides the signals that are used to control jet velocity and charge synchronization. The sensor probe is comprised basically of two rectangular plates. Passing charged drops induce charges on the plates that are proportional to their distances from the plates. The difference in the charge induced in each plate is a function of the misalignment of the drop stream.

We determined that such a sensor would achieve a peak signal level from 128 charged drops, given the parameter values used in our printer. The sensor FET input amplifier required a high (800-MΩ) input impedance and, of course, very low input capacitance (5 pF). To maintain these levels under all operating conditions of temperature, humidity, and ink contamination careful attention to the type of substrate land patterns and coating materials used was necessary. To keep the land and ground capacitances low required driving a guard land with an in-phase signal between all circuit grounds and input lands. With the high dielectric ceramic used for the substrate, the thickness had to be increased to keep the capacitance from sensor land to ground shield low.

The sensors are constructed on a ceramic substrate 1.27 mm (50 mils) thick with the sensor patterns and amplifier interconnections made of thick film gold land and solder pads of platinum gold. Because the sensor is 2.54 mm (100 mils) from the ink stream, a system failure could cause the sensor to be sprayed with ink. Only a few materials can withstand the ink under a severe immersion test. Thus, we coated all sensor patterns with a fired glass passivating material and then coated the discrete amplifier components with a potting material.

Height control

Correct print height is maintained by using signals from the deflection sensor to adjust pump pressure. The pump is driven by 1.8-ms current pulses at 60 Hz. The fluid system time constant is about 1 s, which rejects the 60-Hz pressure ripple. Pulse amplitude is controlled by a signal from a digital-to-analog (DAC) converter and can be controlled over a pressure range of about 20 percent.

A group of 128 drops is charged and deflected through the sensor, passing an equal distance between the upper and lower plates if stream velocity is correct. The deflection sensor and associated analog circuits return a signal indicating the arrival of charged drops at the sen-

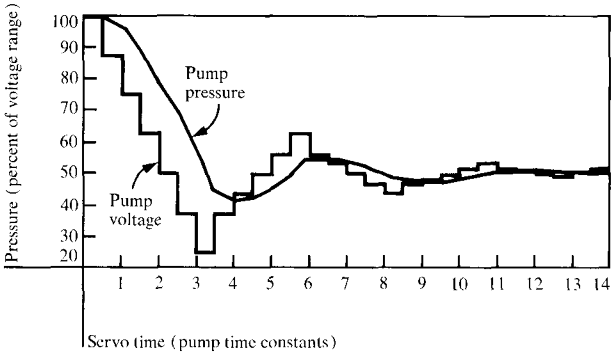


Figure 3 Pump pressure responses to pump voltage changes.

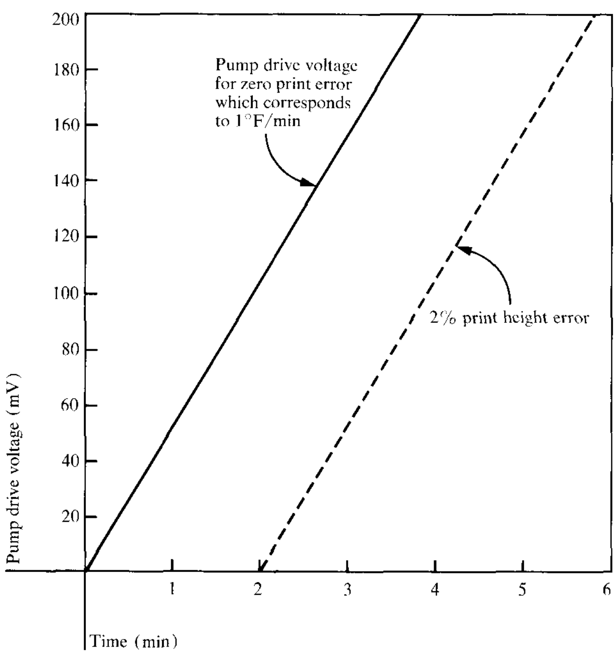


Figure 4 Time between servo cycles.

sor and denoting whether the drops are above or below the sensor gap. An arrival signal initiates integration of the charges coupled from the drops to the sensor.

Output from the deflection sensor circuits via the digital-to-analog converter controls pump pressure.

• *Height correction sequences*
An initial drop sequence establishes correct print height when the printer is first turned on or after a prolonged period without printing. A maintenance sequence, which makes minor corrections, is performed following the printing of each page or after an 80-second interval, whichever occurs first.

To make either type of correction the printhead is driven to the stop at the right-hand frame to ensure that the carrier is aligned with the sensor. The pump control digital-to-analog converter is set to provide maximum ink pressure. Since the temperature is not known, the printer is assumed to be cold; this ensures sufficient stream velocity so that deflected drops do not hit the upper deflection plates.

A group of 128 drops is charged to a level that causes them to pass closer to the sensor plate that indicates a low drop position. The low indication results in a major height correction (one-eighth of the total pump pressure change possible). Then, another group of 128 drops is tested, and another major change in pump voltage is made. This process continues until a high indication is obtained (pump pressure is too low), at which time a major change in the opposite direction is made. Then corrections of half the original amount are made until pressure is again too low. After each transition, the amount of the correction is halved until corrections are only 1/256th of the total pressure correction range, at which time height is assumed to be correct.

For the maintenance sequence, only one test pattern is used, and a single pump pressure change of the smallest size is made. However, if four tests indicate the need for corrections in the same direction, the amount of the correction is doubled to reduce correction time.

Figure 3 represents a computer simulation of pump voltage and the corresponding effect on fluid pressure. The y axis represents the range over which pump voltage, and thus pressure, can be controlled; the x axis represents the servo time normalized to the number of pump time constants.

Simulation of the servo system indicated that print height tests could be made as often as every 700 ms (70% of the 1-second ink system time constant) with no loss in final accuracy. Pressure undershoot did not exceed the initial major correction step size. This method results in a total servo time of between 7 and 17 seconds with an average of 12 seconds.

Several factors were considered in determining parameter values for the servo system. The rate of change of ambient temperature, the maximum temperature range, and the thermal response of the ink system establish worst-case limits of temperature effects on the system. Thus they determine the required maximum rate of change of pump drive voltage. The solid line in Fig. 4 represents the pump voltage required for zero print height error. Another line can now be drawn parallel to this line by assuming, or knowing, the deflection height change for each pump step (e.g., 12.7 μm/step and a 20-

mV/step pump drive voltage change). Thus the dashed line represents the maximum allowable print height change (2 percent). If the servo system can keep pump voltage within this limit, acceptable print quality is assured.

Charge synchronization

To obtain accurate and repeatable drop placement the time that the charge is applied to each drop must be precisely controlled. Because the charging signal has a finite rise time (2-3 μs), large drop placement errors would result if drop separation occurred during this voltage transition period. The phase of the charging signal is shifted to assure that breakoff occurs after the charging voltage has stabilized. (Additional information on charge synchronization is available from [2].)

The four-phase signal shown in Fig. 5 is used to synchronize drop charging to within one quarter of a drop period. Each of the four differently charged signals is used to charge a 128-drop group. Because the drop sensor can detect the correctly positioned group, the correctly phased charging signal can be identified. Incorrectly charged test drops could hit the gutter lip, causing ink deposits to form and a possible system failure. To avoid this problem a pedestal voltage was used to deflect all drops above the gutter with the phased charging signals superimposed above this dc level.

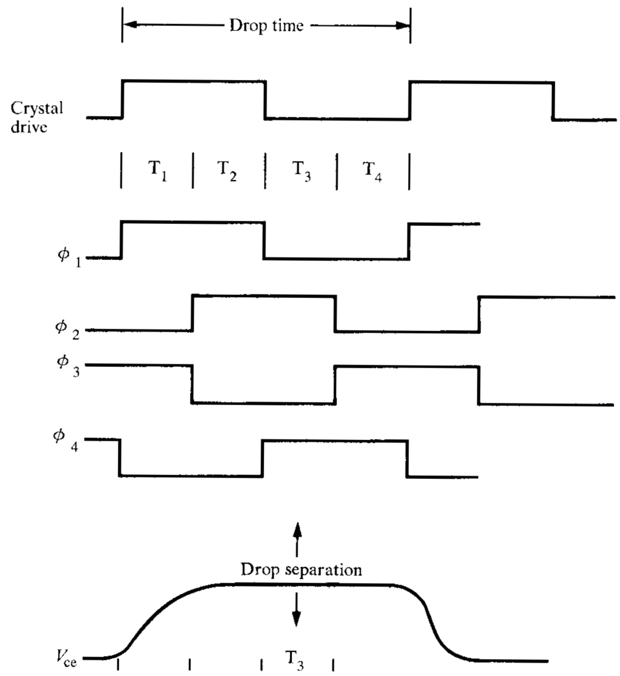


Figure 5 Four phase-shifted drop synchronization signals.

Summary

In this paper we described a sensor capable of sensing the positions of electrostatically charged ink drops. Some of the measures taken to derive useful control information from drops having a charge of about 0.5 pC were discussed. Use of the sensor to control print height was considered next, including the procedure followed at printer start-up and intermittently during operation. Finally, use of the drop sensor for synchronizing drop charging was described.

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