An Optical Method for Drop Formation Stability Measurements of a Continuous Ink Jet

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Abstract

This paper describes an optical method for improved drop formation stability measurement to be used in continuous ink jet printing applications. Stable drop formation is demanded in continuous ink jet printing and it is normally achieved by introducing mechanical vibrations from a piezo electric crystal to the jet emerging from a nozzle. The drops are usually viewed in stroboscopic light to obtain information about the stability of the drop formation. This method does not provide quantified information of the stability of the drop formation and the roughness of the method make analysis and comparison difficult.

In our method we illuminate the drop train with a continuous HeNe laser to create a shadow image of the drops and the information in this image makes it possible to perform quantified measurements of the stability of drop formation. The shadow image of the drops (ø = 15 µm) is magnified and projected onto the light sensitive area of a PIN photodiode based detector whose output is sampled by a digitising oscilloscope. The sampled data is used to calculate the standard deviation of the time between drops and this value is used as a measure of stability.

Our method is developed to measure the stability of drop formation for drops with a diameter ranging from 15 µm at frequencies in the region of 1 MHz. The results of measurements with our method indicate that drops can appear sharp when inspected in stroboscopic light and still have a large standard deviation in time between drops. A flight distance of more than 10 mm is found to radically decrease the stability of the time between drops.

Introduction

The continuous ink jet printing principle is based on the fact that forcing ink through a small nozzle creates a liquid cylinder which naturally breaks up into drops under the influence of surface tension.[1] The natural drop formation frequency is determined by the diameter of the orifice and the ink flow through the nozzle as well as the viscosity, surface tension and density of the ink. The transformation from an ink cylinder to separate drops is initiated by random disturbances induced to the surface of the ink cylinder at the exit of the nozzle. To produce a constant drop formation frequency a piezo electric crystal is fixed to the nozzle introducing larger periodic disturbances than the naturally induced and thus controlling the drop formation frequency.

If an ink jet printer should work properly and reliably it must be fitted with nozzles that are generating drops at a stable and repeatable frequency. To decide if a nozzle is working under these conditions the drops are usually viewed in stroboscopic light. (Figure 1.) Due to fluid mechanic processes during drop formation the velocity of the drops will vary slightly. A more stable drop formation will lead to less variation in drop velocity. The small velocity deviation will result in an increasing or decreasing time difference between the drops along the drop flight path. The time difference will make the drops arrive at the point of measurement at varying times which will make them look smeared when viewed in stroboscopic light. The impact of air resistance will further accentuate the time difference between the drops. The point where the perceived size of the drops viewed in stroboscopic light is about twice as large as at the drop formation point is referred to as “fuzzy point” and should hence be kept outside the position of the paper carrying drum. If the drops appear unsmeared at the distance where the drum should have been positioned in a printer system the drop-generation is said to be stable.

The drawback of viewing the drops in stroboscopic light is that it is almost impossible to get quantified measurements of drop formation stability. Methods based on laser illumination have been presented[2] but they have been applied to fairy large drops, around 200 µm, and low drop formation frequencies, around 50 kHz.

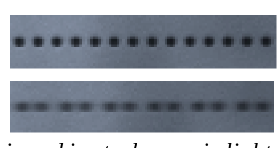

Figure 1. Drops viewed in stroboscopic light at equal distances (10 mm) from the nozzle with high drop formation stability above and low stability below

Presented at *IS&T’s Eleventh International Congress on Advances in Non-Impact Printing Technologies,* October 29-November 3, 1995., Hilton Head, South Carolina.

In this paper an optical method is suggested to provide quantitative examination of drop formation stability for drops with a diameter ranging from 15 μm. This method radically improves the ability to accomplish a quantitative analysis of drop formation stability with various stimulation methods and frequencies compared to the subjective method to view the drops in stroboscopic light. The method has been tested on nozzles with an orifice of about 10 μm working at frequencies ranging from 800 to 1500 kHz.

Materials and Methods

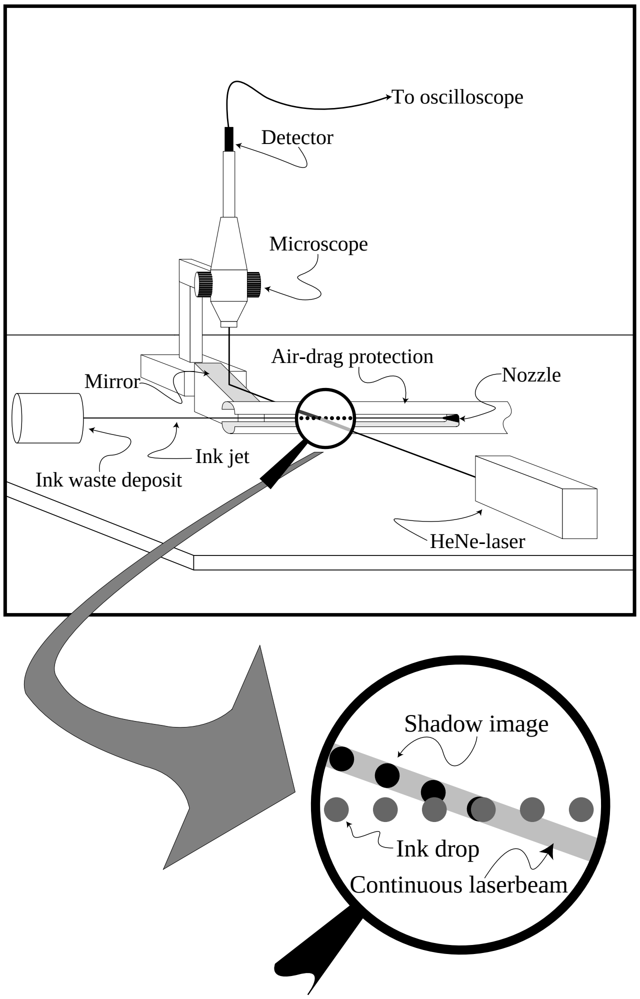

Figure 2. System set-up

Figure 2 illustrates the system set-up. A continuous laser (0.95 mW, HeNe) illuminates the drop train thus creating a shadow image which is reflected by a high reflection mirror through a microscope (Nikon SMZ-2T) to focus on a light sensitive detector. The nozzle is mounted on a x-y-z translation stage which facilitates the positioning of the drop train in the illuminating beam of the fixed laser. The position of the laser illumination and hence the measuring position can be chosen arbitrarily from the tip of the nozzle and 25 mm outwards by moving the nozzle. This distance corresponds to the distance from the nozzle to the rotating drum in an ink jet printer and is therefore the interesting range to perform measurements in. The jet emerging from the nozzle travels through an air-drag protection tube to avoid influence from motion in the surrounding air. The shadow image of the drop (ø=15 μm) is magnified by a microscope to match the size of the sensitive area (ø= 0,4 mm) of the detector in order to get the maximum light-dark contrast an thus providing as large output signal as possible. The sensitive part of the detector is a PIN photodiode (Hamamatsu S2216-02) working in reversed voltage mode. The detection of a drop in the shadow image is represented as a peak at the detector output (Figure 3).

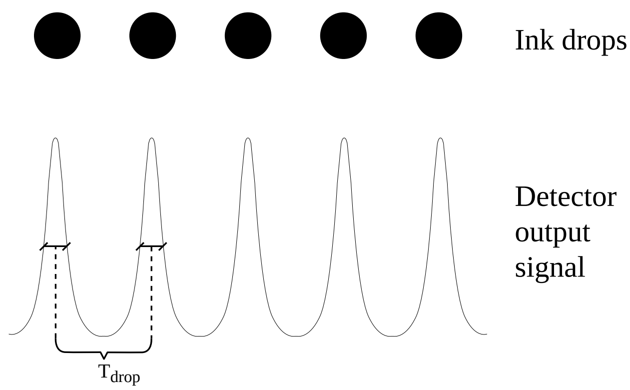

Figure 3. Drops resulting in signal peaks when detected in the shadow image

The detector output signal was sampled by a digitising oscilloscope (HP 54200A) with a sampling rate of 200 MS/s which set our theoretical time resolution to 5 ns. With a drop formation frequency of 1 MHz is it theoretically possible to detect deviations larger than 1.8° of the 360° represented by the 1 MHz period.

The sampled data was transferred from the oscilloscope to a computer (Power Macintosh 8100/110) to calculate the stability of drop formation. The oscilloscope stored 1000 samples recorded at 200 MS/s which made it possible to catch the passage of five consecutive drops at the drop formation frequency of 1 MHz. The computer determined the location of a peak by identifying a rising and a falling edge and calculated the peak centre. From each set of samples it was hence possible to calculate four drop periods (Figure 3) and this was repeated 25 times to include a total of 100 periods in the calculations.

The standard deviation of the drop periods was calculated to be used as a measure of stability. The mean value of the periods was also calculated to make sure that the desired frequency was created. The standard deviation is noted in degrees where 360° represent the period of the excitation signal.

The resolution of the system is theoretically set by the maximum time resolution of the digitising oscilloscope but it is also affected by noise in the measurement system. To determine the noise in our system the continuous laser was replaced by a pulsed laser to excite the detector without a drop train present. The intensity the laser pulses was matched to the intensity of the shadow image. When the system was run under these conditions the standard deviation of the sampled periods was found to be 15 ns in the interval of 800 to 1500 kHz. Thus the noise in the present system reduces the resolution to 15 ns which corresponds to 5.4° of the period of 1 MHz.

The optical method was used to examine the influence on stability of variations in frequency and amplitude of the excitation signal at different distances from the nozzle. Glass nozzles (Siemens-Elema, Solna, Sweden) with an orifice of around 10 µm were used, working with Siemens-Elema storage fluid as ink substitute. The storage fluid has the same physical properties as an ink but it does not contain any dye. The ink was pressurised using compressed air instead of the commonly used piston pump to avoid systematic errors caused by variations in the ink pressure. The system was operated with an ink-pressure of 4 MPa which produced a jet with an exit velocity of 60 m/s. This corresponds to a natural drop formation frequency of 1.3 MHz. External stimulation frequencies in the range from 800 to 1500 kHz were used to find out at which frequencies the nozzles operated at the highest stability. Measurements were also conducted at different stimulation amplitudes.

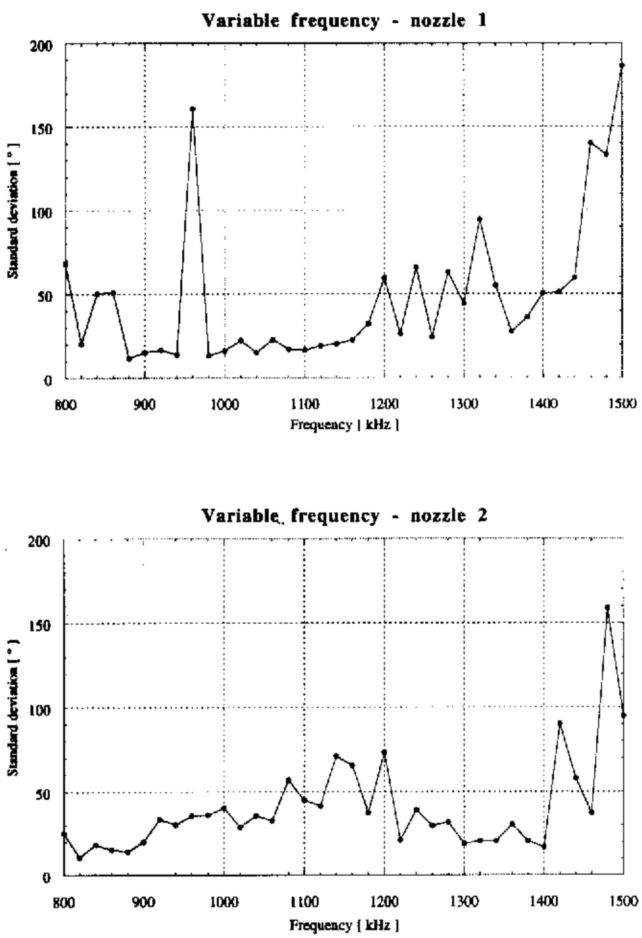

Figure 4. Drop formation stability vs. stimulation frequency for two different nozzles measured at 10 mm distance from the orifice of the nozzle

Results and Discussion

Figure 4 shows the frequency characteristics for two different nozzles measured at a distance of 10 mm from the nozzle tip. The shape of the curves is a result of the combination of drop formation properties of the liquid and the frequency behaviour of both the piezo-electric crystal and the complete nozzle unit. Nozzle 1 (above) has a region of high drop formation stability between 980 kHz and 1.16 MHz. Nozzle 2 (below) is more stable for lower frequencies and in a region between 1.3 and 1.4 MHz.

Figure 5 shows the standard deviation in drop period at different positions along the drop flight path. The results for nozzle 1 are shown at 1.10 MHz and 1.20 MHz drop formation frequencies. The magnification of time difference between the drops caused by the increasing drop flight time should give rise to a linearly increasing standard deviation. However, the air resistance influence the drop flight and causes the almost exponential increase in standard deviation observed. The 1.20 MHz frequency is more unstable which is also seen in figure 4 (nozzle 1). From 10 mm distance and further out there is a radical increase in standard deviation even for the stable frequency due to the exponential behaviour.

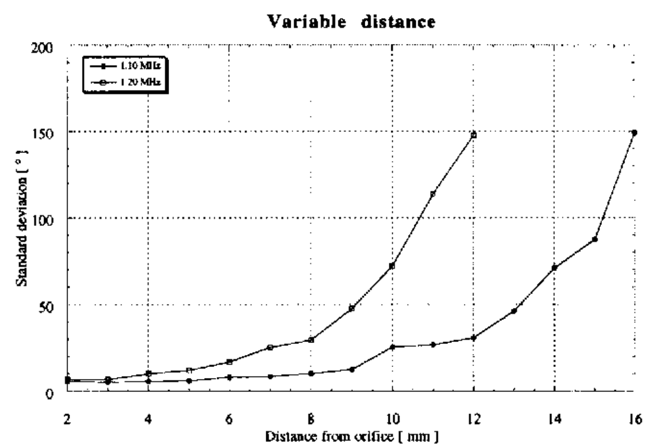

Figure 5. Measured stability at increasing distances from the orifice of the nozzle with two different excitation frequencies. (1.10 and 1.20 MHz)

Figure 6 shows the relationship between excitation voltage amplitude and drop period standard deviation measured at 10 mm distance from the nozzle tip. As expected, the standard deviation decreases with increasing voltage but at voltages above 9 V the standard deviation starts to increase again. This increasing standard deviation is reproducible and is not an error in the measurement. The reason may be that a different mode of vibration is beginning to be excited at those voltages.

In contrast to the subjective method of viewing drops in stroboscopic light the proposed optical method delivers quantified measurements of drop formation stability. There is no observer dependence in the results and it is fairly simple to automate which is beneficial in e.g. production control. The method is clearly more sensitive since a standard deviation of about 75° is needed to perceive a smeared drop which is approximately 14 times the resolution limit of the proposed system.

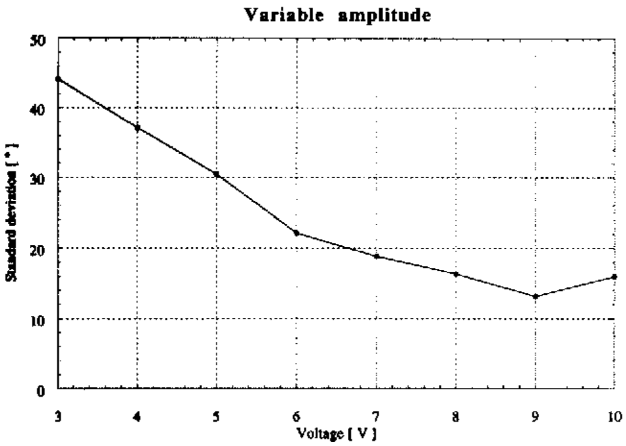

Figure 6. Measured stability with increased excitation signal amplitude at 10 mm distance from the orifice with 0.90 MHz excitation frequency

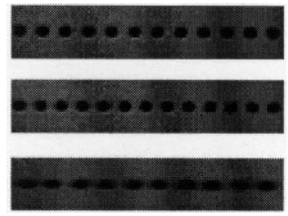

Figure 7. Drops viewed in stroboscopic light at different excitation frequencies. Above 1.10 MHz with measured standard deviation 19.8°, centre 1.20 MHz with measured standard deviation 64.8° and below 0.95 MHz with measured standard deviation 136°

References

1. Rayleigh I.W.S.: On the instability of jets, *Proc. Lond. Math. Soc.*, 4 (1879).
2. Orme M. and Muntz E.P., New technique for producing highly uniform droplet streams over an extended range of disturbance wavenumbers, *Rev. Sci. Instr*. **58**, 279 (1987).