Stimulation Characteristics of Various Diameters of Ink Jets Which Have Equal Amplitude Stimulation

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Introduction

As the demand for higher quality hard copy output increases, the need for smaller print dot size or multibit capability also increases. One method of decreasing the dot size for a continuous ink jet droplet generator is to decrease the size of the orifice. The size orifice required for high quality printing falls in a regime (< 25.4 micrometers) not used by most continuous ink jet companies with the exception of Iris Graphics. The study of the stimulation characteristics of various size nozzles with similar stimulation will aid in the design of future droplet generators.

Theory

The classic paper which describes the instability of a jet of fluid emanating from an orifice was written by Lord Rayleigh[1]. Lord Rayleigh stated that the radius of the perturbed jet can be described by:

$$r = a - be^{q\tau}\cos(kz) \quad (1)$$

The term r in equation 1 is the radius of jet as a function of time and position axially along the jet. The term a is the initial jet radius close to the orifice. The orifice radius is a good approximation to the jet radius for the nozzle shapes and pressures used in our continuous ink jet devices. The term b is the amplitude of the initial perturbation to the surface of the jet at the interface of the nozzle and fluid. This disturbance is generated in continuous ink jet droplet generators by voltage induced displacements of piezoelectric crystals. The assumption will be made that the term b is directly proportional to the root mean square voltage (Vrms) applied to the piezoelectric crystals. t is time, k is the propagation constant $2*\pi/\lambda$, and z is the distance along the axis of the jet starting at the orifice. The term q is a function of surface tension (σ), a, k, fluid density (ρ).

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The value of r is zero at the point where the filament breaks. Equation 1 at the breakoff length can then be written as:

$$a = be^{q\tau}\cos(kz_o) \quad (2).$$

In equation 2, τ and z_o are the time and distance along the jet when the jet breaks off at a disturbance b. Since λ and the frequency can be measured experimentally, equation 2 can be written:

$$a = be^{q\tau}\cos(2\pi f\tau) \quad (3)$$

Equation 3 shows a frequency dependence in the oscillatory part of the equation. When λ remains constant for different pressures, this frequency dependence compensates for the jet velocity change and keeps the breakoff times the same for the same disturbance amplitude.

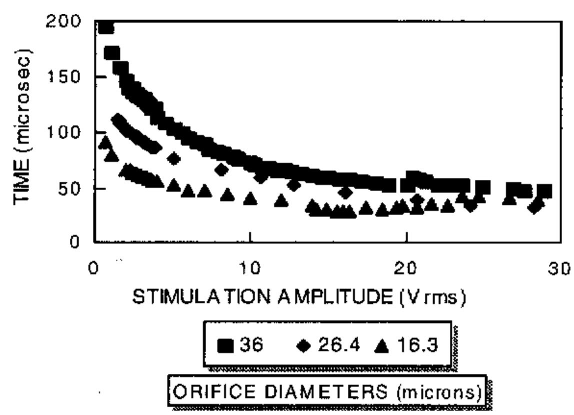

Figure 1. Graph of breakup time versus stimulation amplitude for conditions shown in table I.

In some of the experiments conducted, λ was held constant by varying the applied voltage frequency (f) or fluid pressure (P). The velocity of the jet changes with pressure so that the breakoff length would change even though λ remains the same. The quantity which should remain the same at the same λ value even with varying pressure would be the breakoff time. Since λ is constant for the two pressure situations, then according to equation 3 the breakoff times of the jets should be the same at the same applied Vrms.

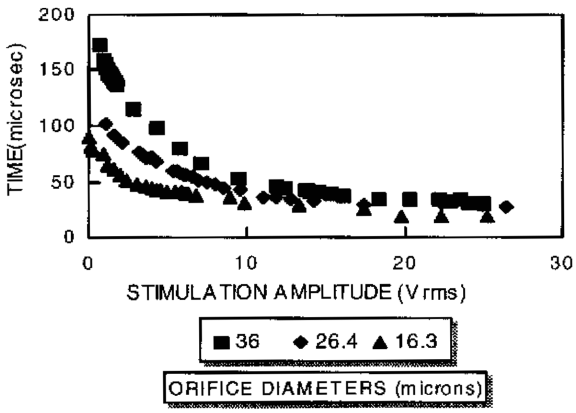

Figure 2. Graph of breakup time versus stimulation conditions shown in table 2

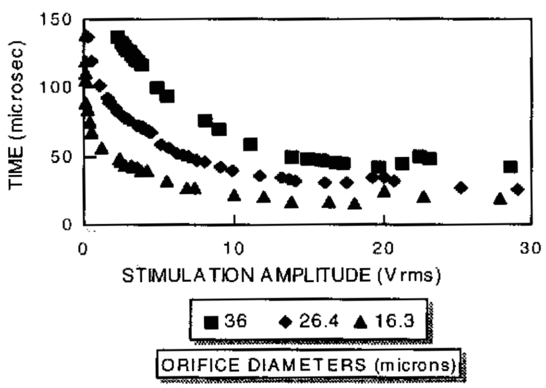

Figure 3. Graph of breakup time versus stimulation amplitude for conditions shown in table 3

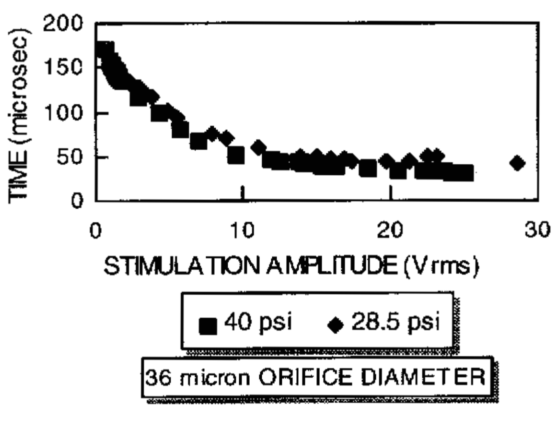

Figure 4. Graph of λ remaining constant by changing either frequency or pressure. See table 4 for conditions

Experiment

An orifice plate was made with orifices varying in size from 16.3 micrometers to 36 micrometers. This orifice plate was bonded onto a fluid manifold which was stimulated by means of piezoelectric crystals. A fluid was used which had a surface tension (σ) of 30.7 dynes/cm and a viscosity (η) of 1.45 centipoise. The breakoff length, taken to be the shortest continuous filament length, was measured by stroboscopic microscopy. The data recorded were the breakoff length (L) versus the Vrms applied to the piezoelectric crystals. The data were recorded for orifices with diameters of 36, 26.4, 16.3 micrometers. Three trials of data were taken with fluid pressure, stimulation frequency, and λ as variables. Two of the three of these were held constant while the third was allowed to vary in each trial. The breakoff times were calculated by dividing the breakoff length by the jet velocity. The data from these three trials can be seen plotted in figures 1 through 3. The values of the orifice diameter(D), fluid pressure(P), stimulation frequency(F) and λ for each trial are shown in the tables next to their respective figure.

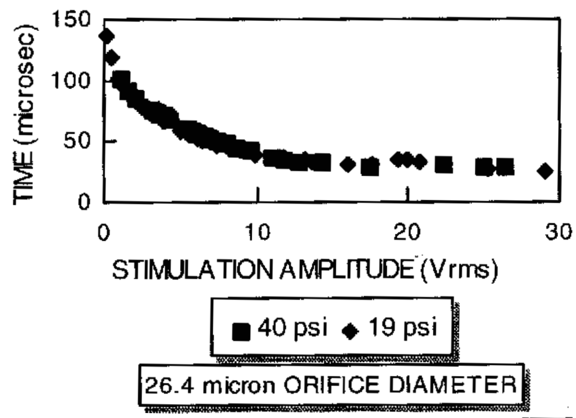

Figure 5. Graph of λ remaining constant with a change of either frequency or pressure. See table 5 for conditions.

Discussion

The breakoff times of the jets can be seen in figures 1 through 6 to be quite dependent on orifice diameter as well as initially on stimulation voltage. As a matter of practicality, the short breakoff times of the smaller orifices become a liability due to the fact that it implies a very narrow gap between the charging electrodes and the orifice plate.

Table 1. Parameters Used in Trial 1.

D microns	P psi	F LHz	λ microns
36.0	40	108	198
26.4	40	108	185
16.3	40	108	176

Table 2. Parameters Used in Trial 2.

D microns	P psi	F LHz	λ microns
36.0	40	131.5	162
26.4	40	169.6	119
16.3	40	246.4	73

Equation 3 does not depend on pressure if λ is kept constant for a given orifice diameter. This would imply that the curves shown in figures 2 and 3 for a given orifice diameter should be identical. Figures 4, 5 and 6 are plots of the breakoff times versus stimulation amplitude at λ/D equals 4.5 with orifice diameters of 36, 26.4, and 16.3 microns respectively. Tables 4, 5, and 6 list the values of the orifice diameter(D), fluid pressure (P), stimulation frequency (F) and λ which identify the data in their respective figures.

Table 3. Parameters Used in Trial 3.

D microns	P psi	F LHz	λ microns
36.0	28.5	108	162
26.4	19.0	108	119
16.3	12.5	108	73

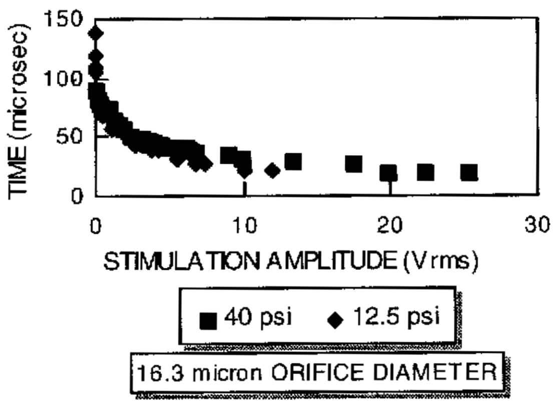

Figure 6. Graph of λ remaining constant with a change of either frequency or pressure. See table 6 for conditions

One reason for this study was to determine if the jet meniscus geometry plays a role in drop formation. This effect is not predicted by equation 1. We theorize that the meniscus geometry is a function of pressure which would imply that the curves in each figure 4 through 6 should not be identical. The curves are not different enough to support this theory. It may be that the meniscus geometry of such small jets is affected little by pressure change.

Table 4. Parameters Identifying Data in Figure 4.

D microns	P psi	F LHz	λ microns
36.0	40	108	198
26.4	40	108	185
16.3	40	108	176

Table 5. Parameters Identifying Data in Figure 5.

D microns	P psi	F LHz	λ microns
26.4	40.0	169.6	119
26.4	19.0	108.0	119

Table 6. Parameters Identifying Data in Figure 6.

D microns	P psi	F LHz	λ microns
16.3	40.0	246.4	73
16.3	12.5	108.0	73

Conclusion

Equation 1 is a good theoretical model describing the instability of a jet. Other methods of modifying the jet meniscus geometry while maintaining the same jet diameter will need to be investigated.

Reference

1. Rayleigh, J. W. S., On the Instability of Jets, *Proc. London Math. Society*, **10**, 1878, pp. 4-13.