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THE EFFECT OF JETTING PARAMETERS ON THE PERFORMANCE OF DROPLET FORMATION FOR INK-JET RAPID PROTOTYPING

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Introduction

Heinzl et al. (1985) reports that experiments in ink-jets to produce drawings or signals occurred as early as 1930. Various companies such as IBM and Pitney-Bowes have conducted extensive studies on these devices for many years. Many such reports are available in such journals as the IBM Journal of Research and Development. While numerous articles have been published on the jetting characteristics of ink and water, the literature is rather limited on fluids such as waxes (Gao & Sonin 1994) or non-water based fluids (Passow, et al. 1993). This present study extends the knowledge base to determine the performance of molten waxes in "ink-jet" type printers for rapid prototyping.

The purpose of this research was to qualitatively and quantitatively study the droplet formation of a drop-on-demand ink-jet type nozzle system for rapid prototyping.

Apparatus

The jet test station used in this study provided the operator with the ability to set, control and record the jetting parameters for an ink-jet drop-on-demand type molten material deposition system. See figure 1.

A frequency generator controlled the firing frequency input to the PC board electronics. A square wave was used to dictate the firing frequency of the droplets. A strobe light illumined the droplets as they were emitted from the piezo-jet. The strobe frequency was adjustable from 500 to 15,000 Hz. The strobe frequency was usually set equal to the jetting frequency except in cases where a lower strobe frequency was used to enable better visual distinction of the droplets on the monitor screen.

An oscilloscope provided the measurement of the firing voltage and firing wave form for the jet. These two parameters were controlled by adjusting two potentiometers on the PC board. The frequency generator controlled the jetting frequency, of course. A frequency counter provided a check on the frequency generator.

A reservoir provided molten material for the jet. Heated and insulated tubing delivered the molten material to the jet. The reservoir, lines and jet were all heated and temperature controlled. Solid build material was periodically added to the reservoir as needed. The reservoir was adjusted so that the liquid level was about 0.5 inches below the tip of the jet.

A video camera fitted with a special lens enabled the high speed images of the droplet jetting to be transmitted to the TV monitor and recorded on the VCR.

Materials and Methods

All equipment was turned on for at least two hours before any data were taken. These data were taken at the following operating conditions representative of this type of RP system:

Voltage ratio = 0.60, 0.70, 0.80, (Voltage ratio = voltage/reference voltage)
Frequency ratio = 2 to 9, (Frequency ratio = frequency/reference frequency)
Duty cycle = min, max, optimum (Duty cycle = firing time/total cycle period)

The duty cycle is defined as the firing time/total time for one cycle. See figure 2. Minimum and maximum duty cycle points were determined visually when the jet stream started to deteriorate. The "optimum" point was some where in between. Voltage readings, and firing times were measured from the oscilloscope. Jet frequency was indicated from the frequency generator as well as the oscilloscope.

Room conditions were approximately: $T_{dry\ bulb}$ = 72 F, 75 % relative humidity. The build material was a proprietary wax that had a melting temperature of about 120 C. All test points were recorded on video tape. Reference distances on the video screen were also recorded on the tape for later determination of droplet diameter, etc.. The time period for each operating point was from 4 to 15 minutes, depending on the frequency. Droplet mass was collected for a given period and weighed on a digital scales to determine the build rate.

Results

Figure 3 illustrates the effect of duty cycle on the build rate at a specific frequency ratio (other frequencies are similar). As expected the build rate has a maximum at some point between the maximum and minimum duty cycles. (Beyond the maximum and minimum points the jet does not fire or the jetting is so poor that it is unacceptable.) On the lower duty cycle end the deterioration of the jet is probably due to the lack of adequate refill time required by the surface tension forces to refill the jet. Poor jet performance on the high end may be due to not having adequate time for the piezo to eject the drop from the nozzle. The optimum jetting conditions are the only ones plotted on the following figures.

Figure 4 illustrates the effect of frequency on duty cycle. It appears that the range of acceptable duty cycles cluster in a range from about 85% on the low frequencies to about 60% at the high frequencies. This seems to indicate that more time is needed to fire the droplet of wax than it does to refill the jet passage with new wax. This effect gradually changes as the frequency increases.

Figure 5 indicates the build rate dependency on frequency. (Ignore for the moment the data at a frequency ratio of 6 and 7.) It is seen that the build rate is approximately linear with frequency; the greater the number of drops (frequency) the greater the amount of build mass. It is also apparent that higher voltages produce a slightly greater build rate. This would seem reasonable since higher voltages would mean greater displacement (volume) of the piezo and therefore greater drop diameter per cycle.

Note that irregular jetting occurred at frequency ratios of 6 and 7. Video inspection of these points indicated that several jet streams were being emitted from the jet at slightly different angles and frequencies. The jet stream was very irregular. It appears that several higher or lower resonant frequencies are existing in the jet at these points which cause the irregular (and unacceptable) jetting. This behavior caused the build rate to be much lower than expected as is indicated in Figure 5.

One operating point was duplicated at a 25 minute interval and the results seemed identical to the smaller time period.

Conclusions

The following general conclusions can be made consistent with the range of variables studied in this program.

1. The build rate (mass/time) is approximately proportional to the frequency of the jet for stable jetting conditions, as expected.

2. The build rate increases with increasing voltage.

3. The droplet diameter increases with increasing voltage.

4. At higher frequencies certain irregularities in the jet stream occur possibly due to particular resonance frequencies occurring in the nozzle. These conditions cause the build rate to decrease.

5. The range of acceptable jet duty cycle for good jet performance ranges from about 60% to 85% with a band width of about 10 to 15 %. The level of the duty cycle decreases with increasing frequency.

References

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Passow, C. H., and Chun, J. -H., (1993) "Droplet-Based Manufacturing," CIRP Annals. v. 42, n. 1, pp. 235-238.

Gao, F. And Sonin, A. 1994. Precise deposition of molten microdrops: the physics of digital microfabrication. Proc. R. Soc. London. A (1994) v. 444, pp. 533-554.

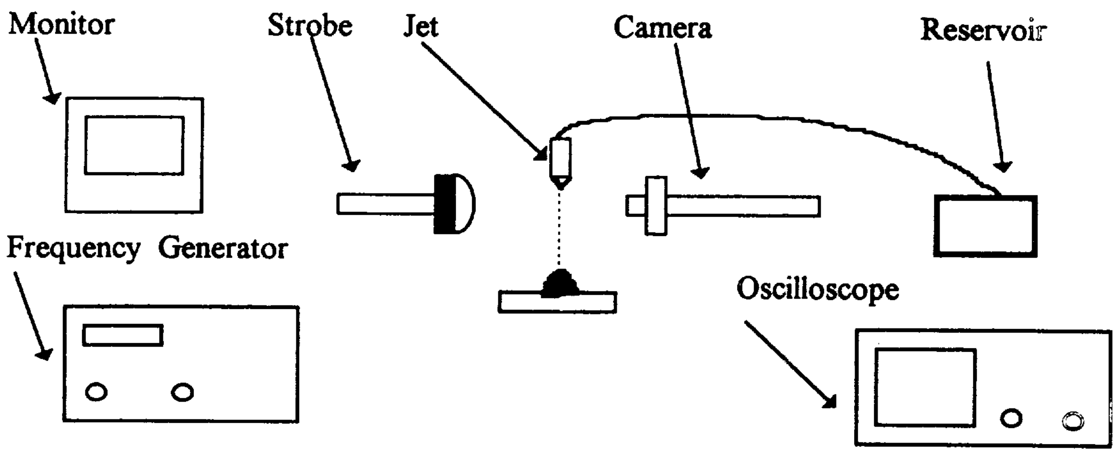

Figure 1 Jet test station.

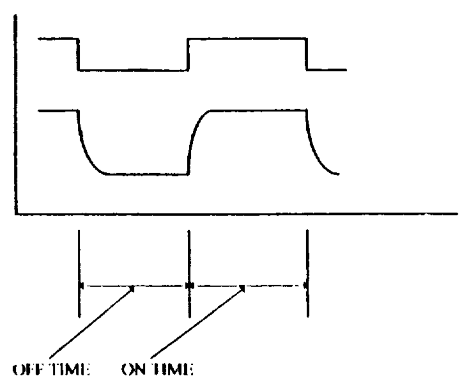

Figure 2. Jet firing profile.

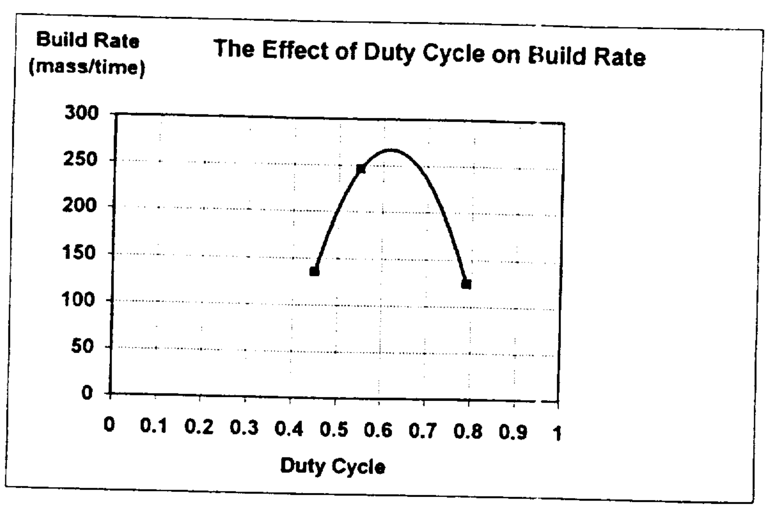

Figure 3. Variation in build rate with duty cycle at a frequency ratio of 9.

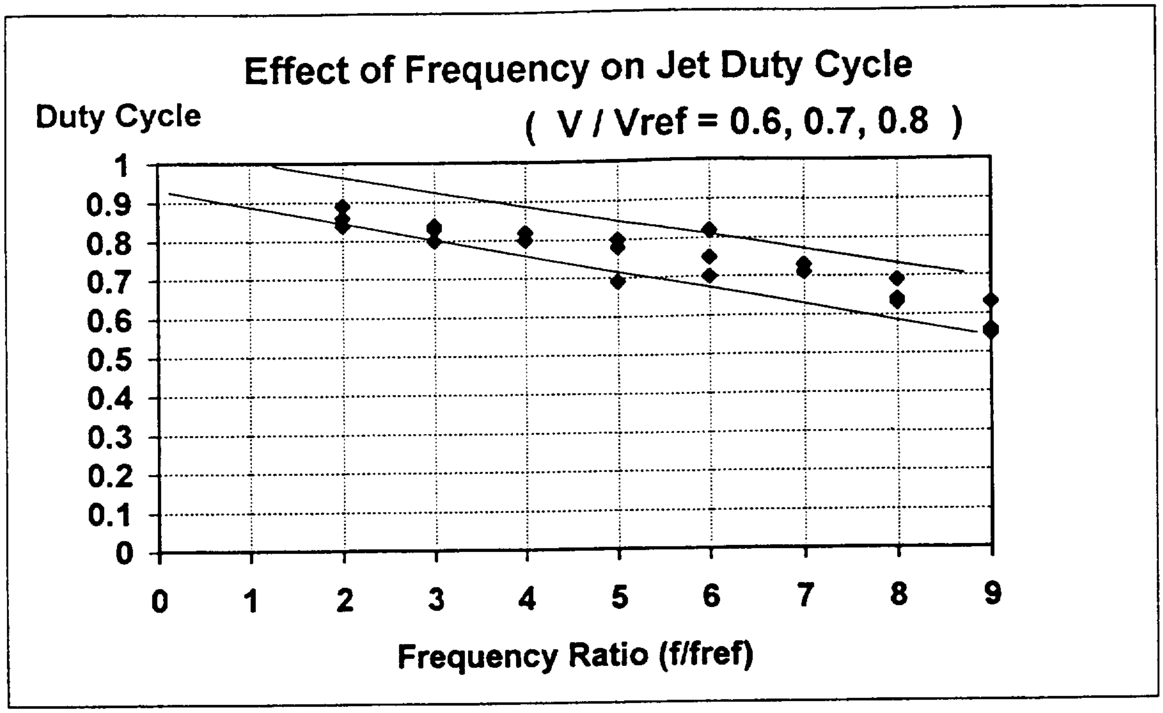

Figure 4. Variation in duty cycle with frequency

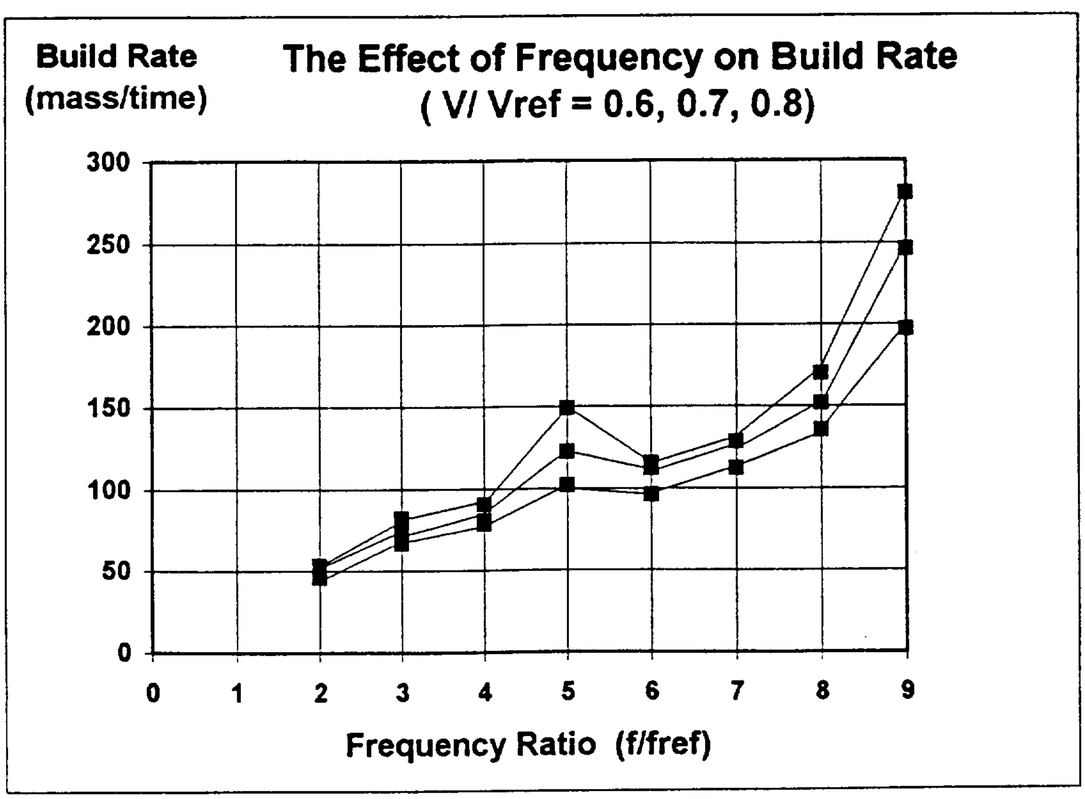

Figure 5. Variation in build rate with frequency.