11.6/11:25 A.M.: The Effect of Pulse Shape on the Drop Volume and the Frequency Response of Drop-on-Demand Ink Jet Transducers

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In drop-on-demand ink jet printing, a voltage pulse is applied to a piezo-electric transducer for each drop that is ejected at the nozzle exit. In Stemme[1] and Zoltan[2], this voltage signal was described as a pulse which must have a short rise time, followed by a slow decay to zero to allow refill of the nozzle prior to the ejection of the next drop. A more complex voltage signal was investigated by Kyser[3], characterized by a sharp initial rise, a subsequent slow decay and a secondary rise to an intermediate level prior to going to zero.

Since the voltage pulse which is applied to the transducer causes a pressure pulse in the fluid chamber, and this pressure pulse, in turn, causes the drop to form at the meniscus, it is apparent that the shape of the voltage pulse should have a significant influence on the drop formation process. In this paper, we study the dependence of the drop formation process on the characteristics of the voltage pulse such as pulse width, amplitude and pulse shape. Using a Motorola 68000 based signal generator, we have observed that the drop volume and frequency response are significantly influenced by pulse width and amplitude of the voltage pulse and almost independent of pulse shape.

Experimental Set-Up

In order to study the behavior of drop-on-demand ink jet transducers, we have used the experimental set-up shown in Fig. 1. It consists of a signal generator to drive the drop-on-demand (DOD) drop generator, a long working distance microscope and a low light level TV-camera with monitor. A strobe light or a LED is used to furnish the light for the camera.

Effect of Pulse Width and Amplitude on Drop Velocity

A pictorial representation of the signal waveforms available from the signal generator is shown in Fig. 2. In each case, the parameters describing the waveform are amplitude and pulse width. In Fig. 3 we show the effect of pulse width and amplitude on the drop velocity for a square wave drive signal. We observe that the velocity of the drops increases with voltage level keeping the pulse width constant. Furthermore, we note that for each voltage value a maximum of drop velocity exists at the same value of pulse width. This optimum value of the drop velocity is observed also for other pulse shapes, as can be seen in Fig. 4. Although the absolute value of the optimum pulse width is not the same for the different pulse shapes shown, we note that the definition of pulse width as given in Fig. 2 is somewhat arbitrary, and, thus, no physical meaning should be attached to the absolute values of the optimum pulse width. It is apparent, however, from the curves in Fig. 4, that the pulse shape that requires the lowest amplitude is the square wave signal, i.e., the signal waveform that has the shortest rise time.

Effect of Pulse Shape on Frequency Response

In Fig. 5 we have plotted the drop velocity as a function of frequency for the following wave shapes: square pulse, sin x/x, a truncated sin x and the error function. For this experiment we adjusted the drop velocity to 3 m/sec at the lowest frequency for all pulse shapes by adjusting the signal amplitude at the optimum pulse width. We observe that the variations in the velocity as a function of frequency are almost independent of the pulse shape, i.e., the maxima and minima in the frequency response plot occur at the same values of frequency regardless of the particular pulse waveform.

Effect of Frequency on Drop Volume

In Fig. 6 the variation of drop volume is shown as a function of drop ejection frequency using the same signals as in Fig. 5. Similar to the case above, we note that the volume extremes occur at nearly the same frequencies at which the extreme values of velocity occur. It is also apparent that the drop volume does not change significantly as a function of the pulse shape.

Effect of Pulse Width and Voltage on Drop Volume at Constant Drop Velocity

In Fig. 7 we have plotted the variation of drop volume as a function of drive voltage and pulse width for constant drop velocity of 3 m/sec. We observe that the drop volume varies by more than a factor of five. Since the velocity is constant in each case, it is apparent that this drop volume variation is an effective means to give half tone printing.

Discussion

From Fig. 5 we observed that the variation of the drop velocity as a function of frequency is almost independent of the particular pulse shape. This result is surprising, since the displacement and the velocity of the transducer as a function of time depend on the time history of the voltage signal. Thus, different pressure distributions should be expected within the fluid cavity for the different waveforms. On the other hand, the pressure pulse that ejects the drop at the nozzle is the integrated effect of the distributed local pressure waves in space and time. Apparently, this integrated pressure pulse is similar in all cases in the present experiment.

The velocity variation with frequency shown in Fig. 5 is a result of the superposition of all pressure pulses within the drop generator from all previously ejected drops. Thus, if a pressure wave from a previous drop ejection is in phase with a current drop ejection, amplification occurs and the velocity of the drop is increased. Conversely, if a wave is out of phase, the velocity is decreased.

If we calculate the drop volume based on momentum balance considerations, the following formula can be derived:

$$V = \frac{1}{4}\, d^2 U\, t_{opt}\left(1 + \sqrt{1 + \frac{32\nu}{U^2 t_{opt}}}\right) \ldots \qquad (1)$$

where d is the nozzle diameter, U is the drop velocity, t_{opt} is the optimum pulsewidth, and ν is the kinematic viscosity of the fluid. In Fig. 8 we have compared the experimental values for the drop volume with those calculated from Eq. (1), and very good agreement is seen to exist for most of the data.

Throughout this paper we have presented the variation of drop velocity and drop volume for synchronous operation of the ink jet. In asynchronous operation, the drop velocity depends also on the drop history, i.e., on the drop pattern generated previously in the particular nozzle. In order to keep the drop velocity constant in this case, the voltage amplitude must be adjusted on-line for each individual drive pulse.

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References

1. Stemme, E. and Larsson, S.G., "The Piezoelectric Capillary Injector - A New Hydrodynamic Method for Dot Pattern Generation," IEEE Trans. ed. 20, No. 1, 1979
2. Zoltan, S.I., "Pulsed Droplet Ejection System," U.S. Patent 3,683,212; August 8, 1972.
3. Kyser, E.L., et. al. Presentation at the 1st International Conference on Non-Impact Printing, Venice, 1981.

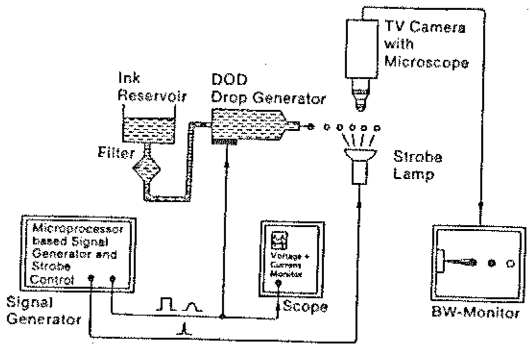

Figure 1. Schematic Of Experimental Set-Up

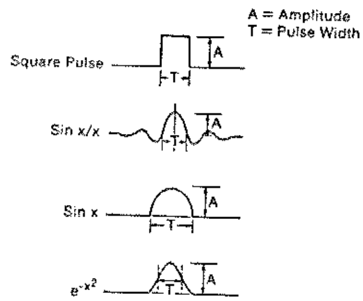

Figure 2. Wave Forms From Signal Generator

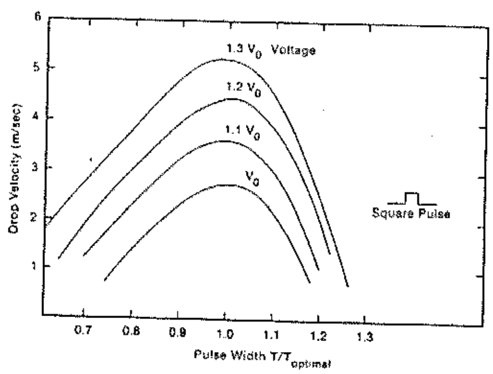

Figure 3. Dependence Of Drop Velocity On Pulse Width And Amplitude

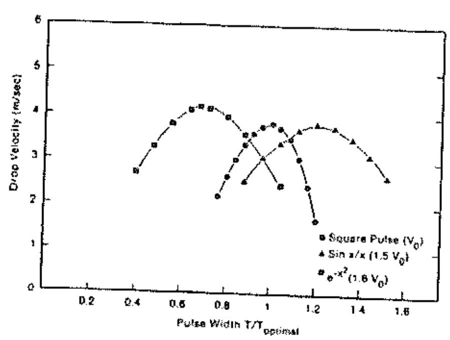

Figure 4. Drop Velocity Versus Pulse Width For Different Pulse Shapes

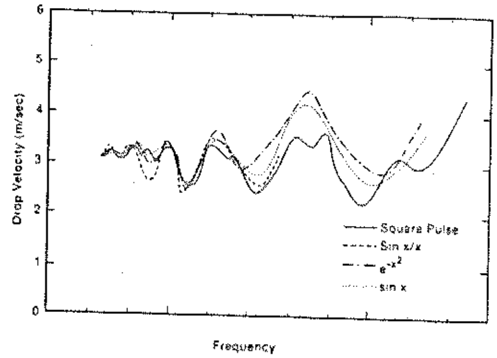

Figure 5. Drop Velocity As A Function of Frequency For Different Wave Forms

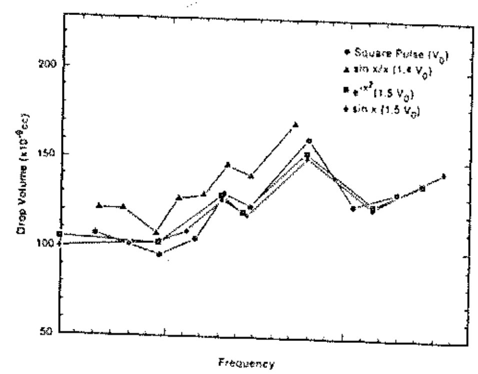

Figure 6. Effect Of Frequency On Drop Volume

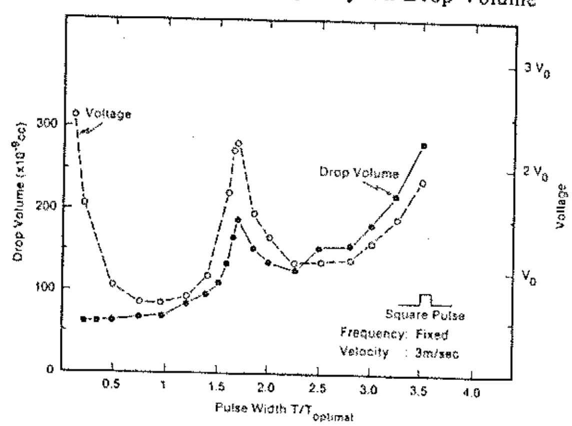

Figure 7. Variation Of Drop Volume As A Function Of Pulse Width And Voltage For Constant Velocity

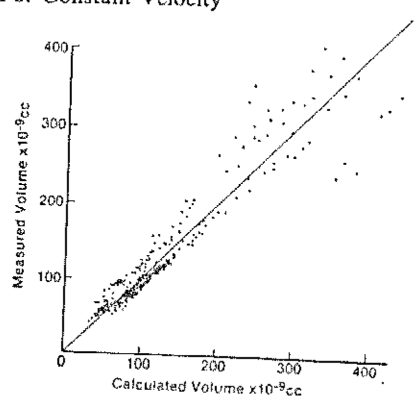

Figure 8. Comparison Of Calculated And Measured Drop Volume