Velocity Measurements of Ink Drops Ejected from a Piezoelectric DOD Print Head—II. Parameters of Ejecting Signal

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The Laser Doppler Velocimetry (LDV) technique was applied to analyze the performance of ink jet printing heads close to operational conditions. This technique yields good statistical description of a large number of drops in a short period of time. An attempt was made to determine the optimal conditions for the printing head operation. The influence of changing the ejection frequency, voltage and pulse-width while changing the location of the measuring point on the velocity statistics were evaluated. The main and lateral velocity distributions were detected. The velocity average in the target direction increases up to about 6kHz and then oscillates. A convex curve was obtained with a velocity maximum related to the pulse width. Increasing the applied ejection voltage significantly affects the velocity of ink drops.

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Introduction

This work deals with velocity measurement of drops ejected from Drop-On-Demand (DOD) ink jet printing heads. DOD print heads eject droplets of ink from a small aperture through the air directly to a specified position on a medium in order to create part of an image. DOD has been implemented in many different designs and has a wide range of applications. Drops' motion was detected by means of an optical technique called Laser Doppler Velocimetry (LDV). Further details on the LDV measurement technique and its utilization to printing-head drops velocities are presented in Blumberg and Semiat's[1] work. A review of the ink jet printing technology is given by Le.[2]

There is very little information in the literature on velocity measurements of ink drops from DOD or similar devices. Many of the experimental observations utilized for the velocity measurement in this field involved the technique of observing the droplets during formation and flight under a microscope using pulsed LED or a simple stroboscope.

Experimental observation of pusher mode print head behavior was conducted by Howkins.[3] For relatively low firing voltages, droplet formation is seen to follow the classical mechanism of an elongated ligament of ink that later in flight, collapses into an oscillating spherical drop. These spherical droplets had a maximum velocity of 4 m/sec in this case. At this velocity, as reported, the droplet aim is very sensitive to sediments from ink or dust that have accumulated on the outside surface of the orifice plate, and the resulting dot placement on the paper is unsuitable for high quality printing. If, however, the drive voltage is increased further until the velocity of the head of the ligament is about 13 m/sec, the aim is greatly improved and the elongated ligament of ink breaks into a number of fragments later in flight without coalescing into a single sphere.

Although this "high velocity" mode of operation results in improved aim, there is the obvious disadvantage that the ligament can reach the paper and form an elongated mark rather than a circular dot. However, in practice it is found that for a wide range of head/paper speed and print gaps the elongation of the dot on the paper cannot be seen by the naked eye. Factors, which limit the elongation of the dot, include a relatively high tail velocity of about 5 m/sec. Dot shape distortion remains a potential limitation. Some limited success has been achieved with experiments to shorten the ligament with pulses after the main drive pulse. The effectiveness of this "wave-shaping" approach, however, depends on many other parameters including orifice size and ink viscosity.

Typical changes in velocity detected by stroboscopic measurements are shown in Howkin's measurements.[3] As the ejection frequency increases above 3 kHz, the head of the ligament starts to collide with fragments from the tail of the proceeding drop. Superposed on this is a series of velocity fluctuations, which become larger in amplitude with increasing frequency. The peaks in Howkin's series correspond to submultiples of the transducer length mode frequency with the exception of the peak that occurs in the vicinity of 30 kHz; this is believed to correspond to the Helmholtz resonance. The magnitude of these fluctuations can be significantly

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decreased by adequate damping of the transducer and/or by increasing the transducer length mode frequency.

Bogy and Talke[4] reported experimental results of the drop formation process using a rectangular voltage pulse. A light emitting diode, which was strobed at the frequency of drop ejection, was used. This freezes the drop and allows viewing on a TV monitor after suitable magnification, by using a video camera. The experiments were carried out on a commercially available cylindrical piezoelectric tube (PZT-5H) in a glass surrounding capillary insert. Results for the low frequency Drop-On-Demand operation range showed the dependence of the operation characteristics on the length of the fluid cavity and the speed of the acoustic wave propagation in the fluid.

The velocity of drops was measured by Bogy and Talke,[4] as a function of synchronous drop ejection frequency. They showed the synchronous drop velocity versus reciprocal frequency for cavity lengths of 12.3 mm, 18.7 mm and 33.9 mm, respectively. In each case, at low frequencies the velocity curves were relatively flat. Under these conditions, a long time elapsed between adjacent pulses and the pressure from one pulse decayed prior to the application of the subsequent pulse. At higher frequencies, there are sub-harmonic resonance and anti-resonance characteristics in the velocity-frequency curves, indicating that a multiple reflecting pressure pulse may be beneficial or detrimental, depending on the synchronization. The period between adjacent peaks is again a function of cavity length. It was also shown in this article that drop velocity at a pulse amplitude of 4.54 V (which gave maximum ejection velocity) versus pulse width for cavity length of 33.9 mm, shows the existence of an optimum pulse width value.

Womac and co-workers[5] reported the performance of a pulsed-chamber with piezoelectric disk uniform-droplet generator that was enhanced through the development of a digital pulse generator system. A trapezoidal pulse signal, variable in terms of peak voltage, rise time, dwell time, and fall time, actuated a piezoelectric disk to force droplets through a precision orifice. Variable pulse control enabled precise delivery of either paraffin oil or water droplets.

The effects of each pulse variable on droplet size and velocity were examined using a Phase-Doppler Particle Analyzer (PDPA) and a photographic technique. The PDPA enables the measurement of droplet size and velocity. Droplet size reported to increase with increased voltage, rise time, dwell time, fall time, etc. Air bubbles in the chamber did not prevent droplet delivery, except for certain combinations of bubble size and location. Dwell time was statistically the most important variable affecting oil droplet size and delivery. Liquid reservoir height was most important for water droplets. Increased pulse voltage tends to increase droplet size and velocity because of increased impulse and momentum.

Takada and co-workers[6] examined the effect of length, width and depth of the ink channel on drop formation. Experimental measurements were carried out on DOD piezoelectric bend mode print head. No information was given on the method of measurement. The results showed the relationship between head dimensions and drop formation. Frequency characteristics strongly depend on the main chamber length. Required pulse amplitude is in inverse proportion to the square of the main chamber width. The drop velocity was examined as a function of the ejection frequency. Two frequencies were identified: high velocity frequency and low velocity frequency.

Gerhauser and co-workers[7] studied the behavior of DOD ink jet transducers. The type of print head is not mentioned. The experimental set up consisted of a long working-distance microscope and a TV camera with a monitor. A strobe light or LED was used to provide the illumination for the camera. The authors checked the effect of pulse width on the velocity for a square wave drive signal. It was observed that the velocity of the drops increases with voltage level, keeping the pulse width constant. Furthermore, for each voltage value a maximum drop velocity exists at the same value of pulse width. This optimum value of drop velocity is observed also for other pulse shapes. Although the absolute value of the optimum pulse width is not the same for different pulse shapes shown, the definition of pulse width is somehow arbitrary, and no physical meaning could be related to the absolute values of the optimum pulse width. An important observation was that variations in velocity as a function of frequency were almost independent of pulse shape. In other words, the maximum and minimum in the frequency response plot occurred at the same values of frequency, regardless of the particular pulse waveform.

The objectives of this work is to demonstrate the capability of the LDV technique, in detecting velocity variations of drops ejected from printing heads, influenced by the different parameters involved. Understanding the statistic problems associated with the system printing-heads-ink will probably lead into future improved printing quality.

Experimental System

The experimental system is described shortly here. A detailed description is given in the preceeding article.[1] The system is divided into three sub-systems:

Drop Formation

Drops were ejected by the contraction of piezoelectric crystals caused by a voltage signal. Ink was supplied to the injection head from the ink tank. A pulse generator enabling the control of the frequency, voltage, rise time and amplitude generated the electrical signal. An oscilloscope was used to view the signal. An air pump was used to fill the injection head before every experiment. During the experiment the air pump was not in use. The ink was flown to the injection head by gravity and the pumping action of the PZT crystal.

Drop Detection System-LDV Measurement

Ink drop velocity was measured using the Laser Doppler Velocimeter described below.[8–10] A 1 watt laser beam from argon ion laser was directed to a Bragg cell device. Two components of the laser beam having wavelengths of 514.5 nm and 488 nm were separated. Each monochromatic beam was split into two parts; a 40 MHz frequency shift was added to one of the beams in each wavelength. The frequency difference between the two beams of the same color gives the ability to distinguish between flow directions.

The four beams were directed via optic fibers to an optical probe. A lens system that focuses the beams to one point in the space was a part of the probe. At the crossing of the beam pairs, interference fringes were created within the intersection volume used for the velocity measurement. A particle that passed the measurement volume, illuminated within the fringes, scattered the light. The back-scattered light was collected by the lenses in the probe and detected by a photo-multiplier tube connected to it. The collected light was separated into two different signals, using filters of two wavelengths. Each individual signal was analyzed by a Burst Spectrum Analyzer (BSA) using a Fast Fourier Transform (FFT) to determine the frequency. The velocities were obtained by multiplying this frequency by the fringes' periodicity, calculated from the wavelength and the angle between the beams. Two BSA devices were used, i.e., BSA1 & BSA2, for the two direction velocities. This gave two perpendicular components of the drop velocity vector.

Data Processing

"Burstware" – a computer program collected data of successive velocities in two directions, calculated the statistics of the flow and sent all data to the PC. The computer also monitored the time of drop appearances and an estimation of transit time, i.e. time duration of the velocity signal. In addition, the software enabled matching (co-incidence mode) between two velocity components that were detected from the same drop. The signals from the two BSAs were viewed on an oscilloscope.

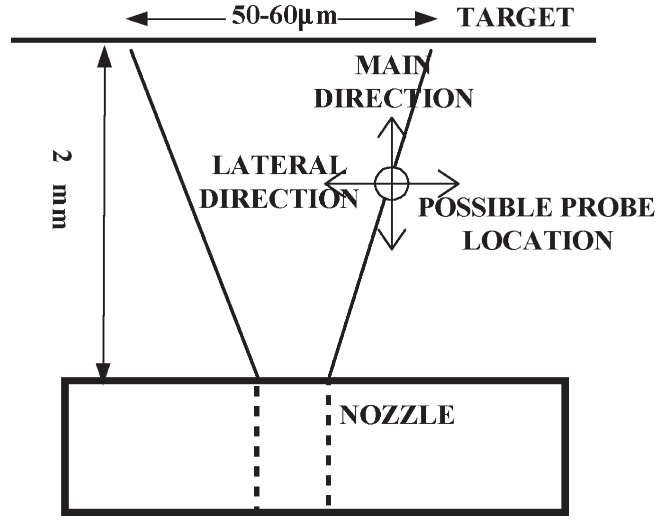

Figure 1. Schematic description of the measurement directions.

Procedure

The ink tank was filled with organic-based ink with blue pigments, with a viscosity of 17.5 cp at 20°C and a density of 1.02 g/cm^3. The optical probe was located above the ink jets so as to bring the measurement volume to the path of a single jet. The probe was located as one pair, of wavelength λ = 488 nm, blue, measured the velocity in the direction of the ejection, and the second, λ = 514.5 nm, green, measured the side velocity perpendicular to the main component of the velocity vector. The regular electrical signal was set to a pulse width of 18 µsec, amplitude of 37 to 38 V, frequency of 1 kHz and 90% of the maximum rise time within 5 µsec. The injection head ran for half an hour before turning off all the nozzles, except the one that was being used for the specific measurement.

The probe was positioned using an *x-y-z* table so that the measurement could be taken at a distance of 0.5 to 2 mm from the orifice plate in the path of the ink jet. The vertical and horizontal position of the ink jet identified as data collected at the highest detection rate and a mean side velocity close to zero.

When clear and stable signals were detected by the BSAs and the oscilloscope, at a chosen set of conditions, the computer was set to collect the data of about 10,000 particles for each parameter. The pulse generator was turned off to stop the operation of the injection head. After about 30 sec break, the pulse generator was switched on and measurements were carried out in a period smaller than 20 sec. The Probability Density Function (PDF) of velocities was presented on the computer. This was considered «short» operation time, simulating real operation, to distinguish between the measurements taken by Blumberg and Semiat[1] where nozzles were operated for longer time—about half an hour, before each measurement.

Measurements were collected at one location, while varying the ejection parameters (from 1 to 18 kHz in different steps) or at one set of ejection parameters while varying the location of the measurement volume. At the end of the experimental session, the pulse generator was turned off and the orifice plate was covered with adherent polyethylene. Experiments were carried out such that the piezoelectric crystals maintained at a temperature of 30°C. The printing head was washed with acetone and dried at the end of each session,

Results and Discussion

Drops velocities reported here were checked for two main parameters. The first is the influence of the measurement position. The second is the influence of generating pulse parameters on the drops velocity. It is important to mention that every point on the figures represents 10,000 drops collected during a measurement session; this allows low statistical error.

Location of Measuring Point

Distance from the Nozzle. The printing target is located around 2 mm from the printing head. It is interesting therefore, to check velocities closer to the printing head in order to track possible changes due to drops separating and emerging during flight. Moving the point of measurement toward the printing head from 2 mm to the closest possible distance from the nozzle, was followed by reduction in performance, however, it was still possible to obtain an adequate data rate.

It is important to note that each new experiment showed different results from the previous one under the same conditions, as will be shown later. It was found that this was attributed to residues of the ink at the surface close to the nozzle. This causes changes in the surface force exerted on the drop, changes in drops' mass, changes in drops' direction and hence changes in the velocity. While this information is known in the industry, it was not reported in the literature. That is the main reason for the spread in the velocities reported here. Because the jets created by the ejected drops tend to travel in the lateral direction, it draws a cone like the one shown in Fig. 1. The cone length is of the order of 2 mm, depends of the target location. Cone diameter varies from close to zero at the nozzle and up to 50 to 60 µm at the target. The main drop stream makes this cone. Figure 1 shows the configuration of this cone. Due to the motion of the drops' jet within the cone it is difficult

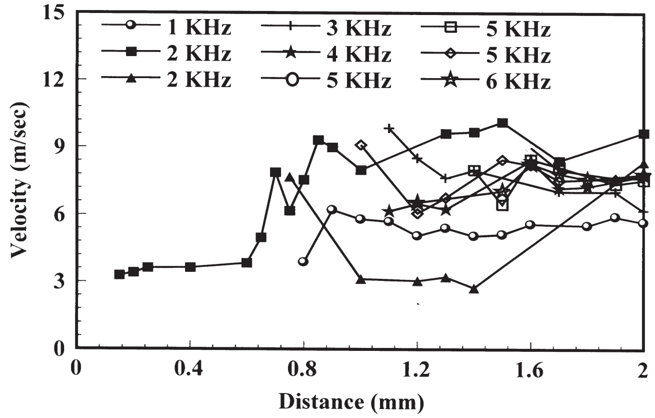

Figure 2. Average main velocity versus distance from the nozzle.

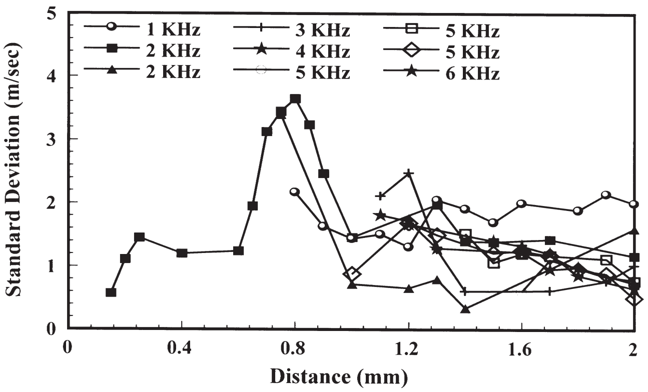

Figure 3. Main velocity standard deviation versus distance from the nozzle.

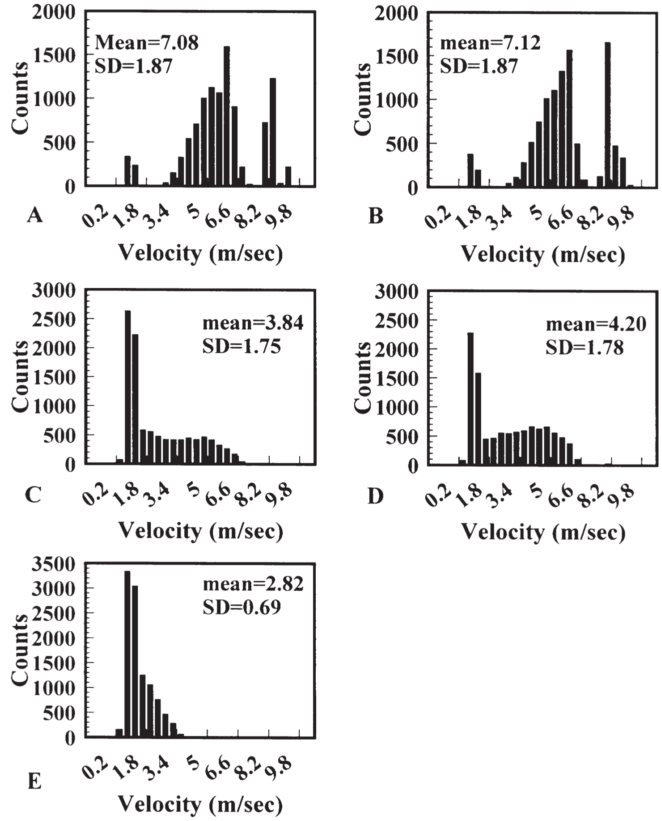

Figure 4. Main velocity of ejected drops, at distance of 2 mm from the nozzle in different lateral locations; (A) relative zero point; (B) 0.01 mm; (C) 0.02 mm; (D) 0.03 mm; (E) 0.035 mm.

to locate the measurement volume exactly at the same position.

Figure 2 presents values of the average velocities along the axis of the cone or close to it. The curves end at a distance where it is not possible to measure due to low data rate. The figure shows the average velocities as a function of different ejection frequencies (between 1 to 6 kHz), at different distances from the nozzle, 2 mm apart and closer to the nozzle.

For all the experiments exhibited in Fig. 2, the maximum average main velocity was 10.1 m/sec for the series of 2 kHz at a distance of 1.5 mm from the nozzle. The minimum velocity was 3.05 m/sec for the series of 2kHz at 1.2mm from the nozzle. The main velocity standard deviation as a function of the distance from the nozzle is presented in Fig. 3. The maximum standard deviation was 3.6 m/sec for the series of 2 kHz at 0.8 mm from the nozzle. The minimum standard deviation was 0.3 m/sec for the series of 2 kHz at 1.4 mm from the nozzle. Again, it should be noted that the lack of repeatability in the measurements from session to session is probably due to the accumulation of ink on the nozzle plate and the inability to isolate all the parameters, especially the lateral location.

Effect of Lateral Location. Measurements were collected at a distance from the nozzle plate while changing the lateral location of the measurement volume up to the point where it was not possible to obtain sufficient data. An example of the influence of the lateral location is shown in Fig. 4. This figure represents the PDF of the ejected drops main velocity, at a distance of 2 mm from the nozzle in different lateral locations. Fig. 4A was chosen to be the relative center point for this specific measurement and Fig. 4B,C,D and E show lateral movements of 0.01 mm, 0.02 mm, 0.03 mm and 0.035 mm, respectively from the location in Fig. 4A. While Fig. 4B shows a very similar picture to Fig. 4A, the picture changes with the lateral distance. It is obvious from the data that different lateral locations give different distributions under the same conditions. Aside by 0.035 mm, the velocity changed from 7 m/sec to 2 m/sec, and the distribution shape changed from a three-peak distribution to a wide one-peak distribution and finally to one relatively narrow distribution.

This presentation supports the claim of the shaped cone as suggested in Fig. 1.

Influence of Pulse Parameters

This section presents the results obtained for the velocity statistics, average and standard deviation for both the main and the side velocities while changing the ejection pulse parameters. The different parameters changed were the pulse voltage and the pulse width for different pulse frequency, while all other parameters were kept constant.

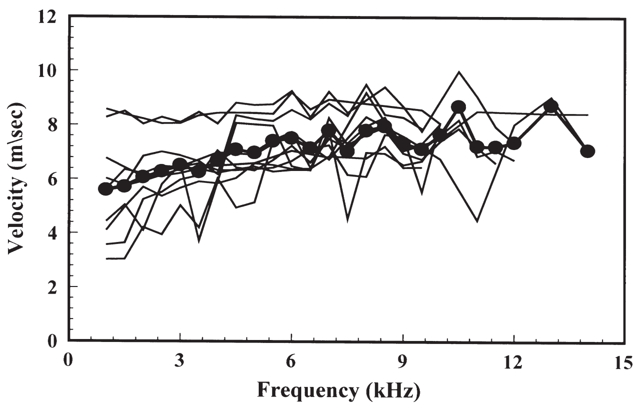

Figure 5. Average main velocity versus ejection frequency.

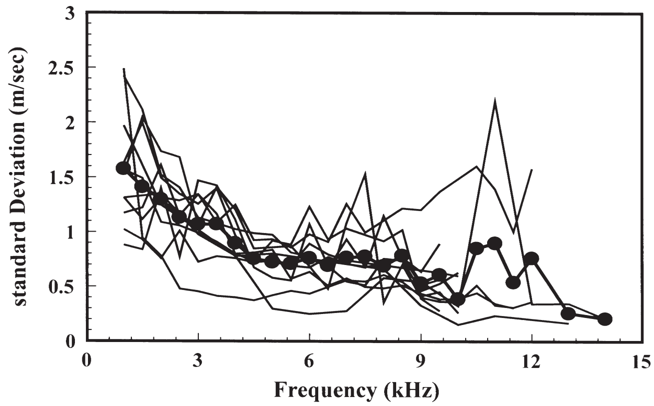

Figure 6. Average standard deviation of the main velocity versus ejection frequency.

Ejection Frequency. An average velocity was found at various frequencies for the velocity of 10,000 collected particles for each experimental point. As seen before, the results' repetition at different sessions was not so good, so a "summarizing average" was calculated, an average of all average velocities of the same frequency, to aid in comparison among various operational conditions.

The summarizing average of the main velocity and the average of the main velocity are presented as a function of the ejection frequency in Fig. 5. The bold line with circles in this figure represents the summarizing average of the main velocity. The other eleven curves are the average of the main velocity; each curve represents one working session of the experiments under the same conditions.

The summarizing average velocity is increased with the ejection frequency up to about 6 kHz. Then it starts to fluctuate around more or less constant velocity. Such general trend of velocity fluctuations as a function of frequency is reported in the literature (Howkins,[3] Bogy and Talke,[4] Womac and co-workers[5] Takada and co-workers[6] and Gerhauser and co-workers[7]). However, for the velocity measurements of Howkins[3] that were performed on a similar print head as in this work (piezoelectric pusher technology), the magnitude of the velocity and its fluctuations are different from those that were observed in Fig. 6. Howkins's velocity measurements, conducted using stroboscopic light, suffer from a lack of statistical analysis. It is believed that measuring with the stroboscopic light method, due to its nature, enables the detection of averages of only some of the velocity populations that exist among others, in a normal print head operation.

Howkins[3] claimed that the velocity peaks correspond to submultiples of the transducer length mode frequency. Based on that, the peaks in Fig. 5 may correspond to submultiples of the transducer length obtained in this work. The peaks' spacing corresponds to Howkin's presentation, starting from about 6 kHz with peak spacing at about 1 kHz, with peak spacing growing gradually to about 2 kHz at 10 kHz.

Figure 5 exhibits the problem of repeatable results. It is believed that the main reason for that is the left over ink at the surface of the nozzles. It was impossible to isolate the effective parameters that cause the spread of the results. The maximum average main velocity was 10 m/sec, the minimum was 3 m/sec with an average of 7.1 ± 1.08 m/sec. Most of the results were between 6 to 9 m/sec. It can be seen that in some cases, higher velocities were measured, almost insensitive to the ejection frequency. That leads to think that there might exist some conditions where proper operation will yield better results.

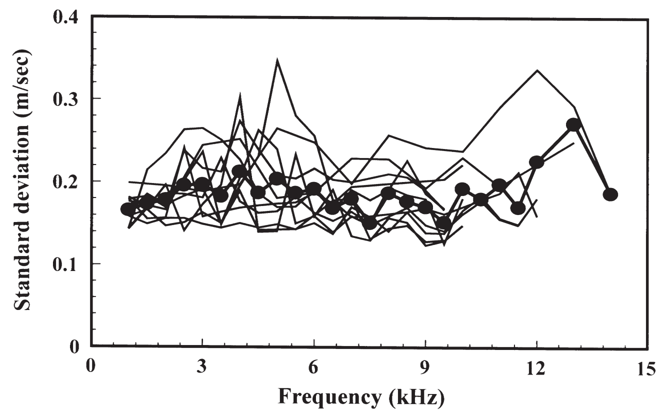

Figure 7. Average standard deviation of the side velocity versus ejection frequency.

The average standard deviation for the main velocity is seen as a function of the ejection frequency in Fig. 6. It can be seen that the standard deviation of the main velocity declines when the frequency rises. The standard deviation increases as a result of multiple peak distribution, in other words the low ejection frequency had the tendency to produce more multiple peak distribution than the high ejection frequency. The range of the standard deviation was 0.6 to 1.2 m/sec with an average value of 0.86 m/sec, which is about 12% of the main velocity.

Because it was difficult to adjust the laser measurement volume at the same position as the ejected jet, the average side velocity was not equal to zero. The side velocity was therefore corrected to a mean value of zero by subtracting the initial average value. The values of

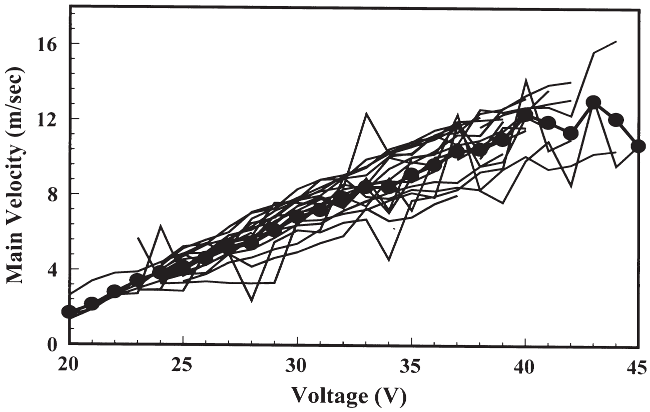

Figure 8. Average of the main velocity versus ejection voltage.

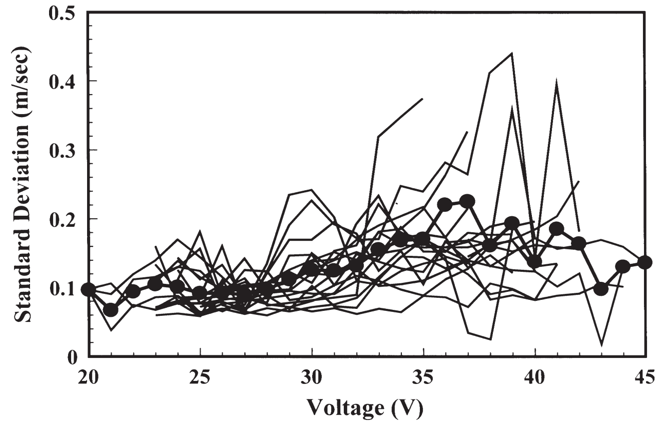

Figure 10. Average standard deviation of the side velocity versus ejection voltage.

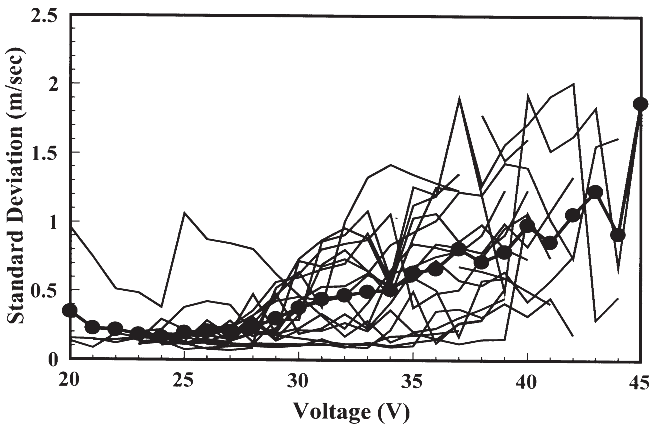

Figure 9. Average standard deviation of the main velocity versus ejection voltage.

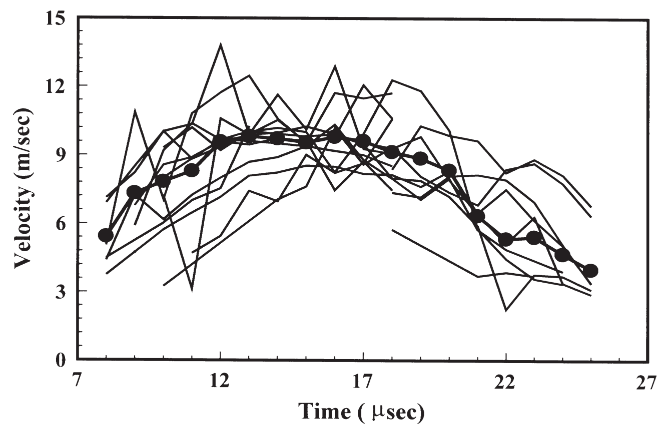

Figure 11. Average of the main velocity versus ejection pulse width.

the main velocities were not changed because the influence of the error in the probe position in this direction is negligible. At a zero average of the lateral velocities, only the mean standard deviation was calculated at every frequency and presented in Fig. 7. The values of the STD exhibited a constant behavior with a range of 0.19 ± 0.03 m/sec.

For drops at velocities of 6 to 8 m/sec, where the error estimation is assumed to equal σ, the standard deviation, the scattering of drops on the roll of paper that moves at 1 m/sec is 0.25 to 0.33 mm in the paper direction. The maximum distance between the drops directed to the same point is therefore 0.08 mm. The drops' scattering in the lateral direction for standard deviation of 0.16 to 0.22 m/sec (which is the range of standard deviation obtained from the side velocity), is 0.04 to 0.06 mm. These values determine the resolution of printing.

Ejection Voltage. The average main velocity and the corresponding standard deviation are seen as a function of the ejection voltage in Figs. 8 and 9. Twenty-eight curves are presented; each curve represents one working session of the experiments. As was already emphasized in the previous sections, differences in the velocity and standard deviations occurred between measurements performed under the same conditions.

The summarizing average of the main velocity as a function of the ejection voltage, shown in Fig. 9, presents a positive rising trend line, which is almost linear. In theory, the higher the applied voltage is, the stronger the piezoelectric crystal deforms. Consequently, the force that acts to eject the ink is stronger. Therefore, the drop velocity is expected to be higher. This is in agreement with Womac and co-workers,[5] who also observed droplet velocity increase with elevating pulse voltage. Measurements done by Womac and co-workers[5] utilized the Phase Doppler Particle Analyzer (PDPA) to measure simultaneously the droplet size and velocity. The average main velocity for a pulse voltage of 20 V was about 2 ± 0.16 m/sec. This value was constantly increased up to the maximum value of 12 ± 2.01 m/sec obtained at a pulse voltage of 43 V. Womac and co-workers[5] also detected a range of velocities for every pulse voltage. They obtained a standard deviation of up to 50% of the main velocity. The standard deviation calculated in this work reached a value of 20% of the main velocity. The standard deviation tends to increase with the pulse amplitude as shown in Fig. 9. For low voltages, the main

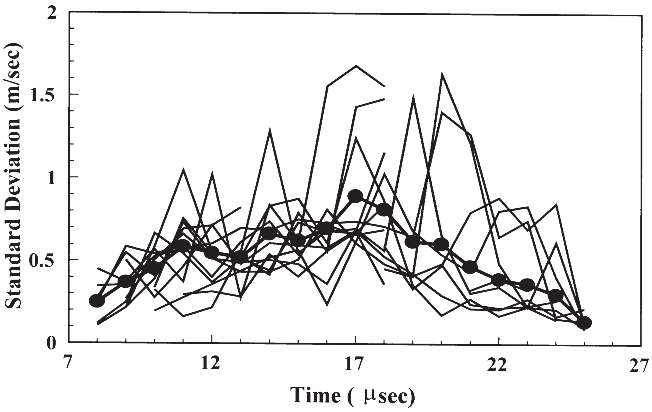

Figure 12. Average standard deviation of the main velocity versus ejection pulse width.

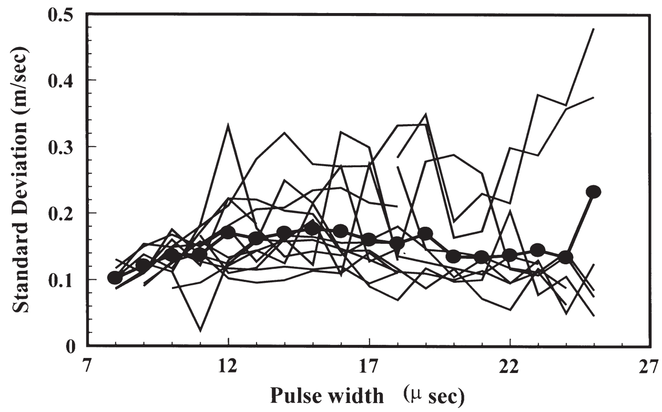

Figure 13. Average standard deviation of the side velocity versus ejection pulse width.

standard deviation was 0.25 ± 0.2 m/sec and increased to about 1.75 ± 0.2 m/sec for 43 V.

The mean standard deviation for the side velocity was calculated at every voltage and is exhibited in Fig. 10. A slight elevation is seen with pulse voltage. Except for one set, most of the results fall in a narrow range of 0.05 to 0.2 m/sec for pulse voltage of 20 to 44 V. The average error estimation for the mean side velocity standard deviation was 0.05 m/sec.

Discrepancies in the velocity and standard deviations that occurred between measurements performed under the same conditions may have resulted also from the change in the lateral location of the measurement that occurred due to movement of the drop jets as explained before.

Ejection Pulse Width. The average main velocity and the summarizing average of the main velocity are seen as a function of the ejection pulse width in Fig. 11. Fourteen curves are presented; each curve represents one working session of the experiments. A convex curve with a velocity maximum behavior of the summarizing main velocity with respect to the pulse width indicated in Fig. 11, was also observed in the works of Heinzl and co-workers[11] and Bogy and Talke.[4] Both studies used light emitting diodes strobed at the frequency of drop ejection. Short pulse widths are not long enough to agitate the piezoelectric transducer. A pulse width that is too long prevents the transducer resonance from damping before the next pulse segment. Regarding the main velocity, the optimum pulse widths, which are the values that gave the highest velocity, were from 12 μsec to 18 μsec. The lowest velocity of about 5.5 m/sec was obtained for a pulse width of 22 to 25 μsec. The average error for the summarizing main velocity was 1.7 m/sec. The lowest error (0.7 m/sec) for the main velocity was obtained for 15 μsec where the velocity is in the optimized range.

The standard deviation seems to follow the same tendency as the main velocity, is shown in Fig. 12. A main velocity standard deviation elevation was observed at a pulse width of 14 to 18 μsec. These values correspond to the increase in the main velocity itself. On both margins of this figure, the main velocity standard deviation was 0.2 to 0.8 m/sec. In a pulse width of 15 μsec to 18 μsec, the main velocity standard deviation was increased up to 1.7 m/sec. The main velocity standard deviation deviated by 0.24 m/sec.

The mean standard deviation for the side velocity was calculated at every pulse width. The mean side velocity standard deviation is exhibited in Fig. 13. Mean side velocity standard deviation exhibits a constant behavior with the pulse width. The mean standard deviation for the side velocity exhibits a constant behavior with the pulse width seen in Fig. 13. Mean side velocity standard deviation was 0.05 to 0.25 m/sec. Again, higher values were observed in the range of 12 μsec to 18 μsec. The average fluctuation for the side velocity standard deviation was 0.05 m/sec.

Conclusions

The LDV technique was applied to measure two directional ink drops' velocity close to the target at close to real operational conditions. It was found that a drop's cloud is formed in time toward the target, presenting a cone shape. The swarm of drops oscillates in space. Within the cone shape of the drops' swarm exist different types of velocity distributions at different locations and times. Ink accumulation close to the ejection nozzle was observed during the experiments. It is believed that this ink left over is responsible for the oscillating type behavior of the drops' swarm and to the changes in drops' velocities.

Assuming that the standard deviation of the velocity multiplied by the flight time is a good estimation for the resolution obtained, the results shown here, for the condition applied, present a resolution of the order of ±0.06 mm for the main direction and ±0.03 mm for the side direction. Those are tolerable for wide format printing.

It appears that short pulse duration is not enough to agitate the piezoelectric transducer. Too long pulse duration might cause a situation where the transducer resonance is not damped before the next pulse segment arrives. This introduces a convex curve with a velocity maximum related to the pulse width. The higher the applied voltage, the stronger the piezoelectric crystal deforms. Consequently, it increases the velocity of ink drops.

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