Better Products Faster

Demonstration of a Novel Technique for Characterization and Quantification of Inkjet Performance

James Fox
Xennia Technology Ltd.
Royston, Herts, United Kingdom

Abstract

Inkjet printing has long been considered a "black art" with a limited number of "magical" materials and combinations thereof known to a few individuals as giving highly reliable jetting performance. For many years experience and excessive testing of many materials predominated as the only guaranteed route to inkjet reliability and success. Recent years have shown a significant increase in the application of more scientific methodologies in attempts to understand the inkjet process and the fundamental parameters governing it. Many people within the industry are now using optical techniques to examine and visualize print head performance. Beyond visualization the next steps are characterization and measurement - a new technique has been developed to take those steps.

The aim of this paper is to demonstrate the applicability of a novel technique specifically developed to quantify inkjet printing performance in all areas, from developing more robust and higher performance products to more meaningful quality control of existing products. This study demonstrates the range of different performance features that may be examined across the breadth of inkjet print head technologies and how this data may then be used in assessing reliability and defining key system parameters such as print head drive conditions and maintenance algorithms.

Introduction

It has long been understood that beyond simple fluidic physical properties many factors come into play in reliably jetting an inkjet fluid. Such fundamental parameters as viscosity (Brookfield) and surface tension (static) are always measured and quoted for an inkjet fluid and yet provide no guarantee of success or reliability. More recently, in an attempt to bridge the gap in understanding between basic physical properties and the inkjet performance achieved, effort has been seen in three areas – more representative physical property measurement, system modeling and visualization/characterization equipment.

Physical property measurement under conditions more akin to those experienced in the print head during droplet ejection are possible with modern high shear viscometers and dynamic surface tension equipment. Inkjet is a truly dynamic process, with such a wide range of shear forces experienced; from the dormant ink in the ink tank, to flow through the manifold and filter media into print head capillary channels and then finally ejection through the print head nozzles. Shear rates varying from 0 to 10^{-5} or $10^{-6}s^{-1}$ are experienced over very short timescales - this level of shear is akin to that experienced in a high performance engine!

Mathematical modeling has been significantly fine-tuned from the early days of the simple application of the Rayleigh equation to describe break-up of a fluid stream into discrete droplets and evidence is available as to the power of this technique in papers describing the design of higher performance drive waveforms[1].

Both of the above methods are predictors of performance, for these to be further developed and their accuracy understood, one final technique is key - characterization. Prediction of performance may only be improved if the actual performance achieved is determined, quantified and then used to further fine-tune the theory. From the use of simple camera and strobe systems, through to newer high-speed camera techniques, the droplet ejection process has been observed in an effort to gain further understanding[2]. However, there are a number of weaknesses in camera based approaches and therefore it is highly desirable to have an improved technique that generates quantified characteristic data on individual droplets, incorporating the flexibility to drive a wide range of inkjet print heads and modify the driving parameters. A new laser based instrument has been developed to provide these benefits and is the subject of this paper.

Characterization

In order to quantify the key inkjet parameters of droplet volume and velocity on an individual droplet basis and display a profile of the ink stream and break-up, a laser based system has been developed and is referred to as the "VisionJet Genie".

Design Requirements

The design and development of the Genie system was aimed to address the deficiencies of camera/stroboscopic techniques and also to allow certain key experiments to be performed, which had previously proved difficult to do accurately or were simply not possible at all. The key requirements were-

1. Quantitative data. A system that produces quantitative output is very important, traditional camera/strobe techniques generate images of the jetting process and interpretation of this data is heavily reliant on the experience and expertise of the operator. It is also difficult to communicate this data to others and assign any kind of pass/fail criteria or specification when the interpretation is so highly subjective. Quantitative data maybe generated from images but this is a laborious process and so there is great benefit in a system that automatically generates such quantitative output.
2. Individual droplets. In a camera/stroboscopic system, the pictorial data collected is actually an average of many drops as the camera shutter speed or refresh rate is insufficient to capture data for a single drop. The definition of the drop outline is often poor and blurred due to differences between the drops that have been averaged. Also, one-time events such as satellites or aerosols maybe missed completely as the averaging process "washes" them out of the image. In defining the reliability of an inkjet printing system, it is these one-time events and the degree of variability that are often of most interest. Also, it is important to note here that the outline profile of the ink stream is really the only important part of the image captured; most of the actual data captured is irrelevant (i.e. the gray scale of the drop itself, the background image, etc). This irrelevant data simply limits the rate at which images maybe captured. The Genie system avoids this issue by simply capturing the required data; the droplet profile. This allows data to be captured at a much higher rate (so each individual drop maybe quantified).
3. Flexibility of the print head driver design. Inkjet printing encompasses a number of technologies and a broad range of implementations, which the system must support. The driver electronics were designed to allow many different print heads to be tested and parameters such as driving voltage, firing frequency and drive waveform to be tailored to suit the fluid properties and provide the highest possible reliability. In the early days of inkjet, drive signals were mainly very simple energy pulses, now this is far from the case. Thermal print head developers are using pre-pulses or sub-ejection pulses to maintain a constant, elevated temperature in the nozzle, thereby reducing the fluid viscosity and also ensuring a more constant viscosity (less affected by changes in ambient temperature). Piezo manufacturers are developing multi-component waveforms to aid the channel refill process and control droplet break-up giving higher firing frequencies. The system allows design of any customized waveform, so that the effects of all these techniques may be characterized and optimized.

Theory of Operation

A HeNe 638.2nm, 30mW, Class 3b laser is used to illuminate the droplet. The laser beam is taken through 180° by a two mirror system to reach a beam splitter. The beam is then split and optically processed to give two very thin parallel slits of laser light, which finally pass through a lens and are focused to a point after which they diverge ending incident on the two photodiodes. By sampling the "shadow" cast by the droplet on the photodiode, the software can reconstruct an outline image of the droplet in flight. Figure 1 below shows cross sections of the laser beam as it passes through the different optical components of the system, which shape and focus the beam to provide the optimum output signal.

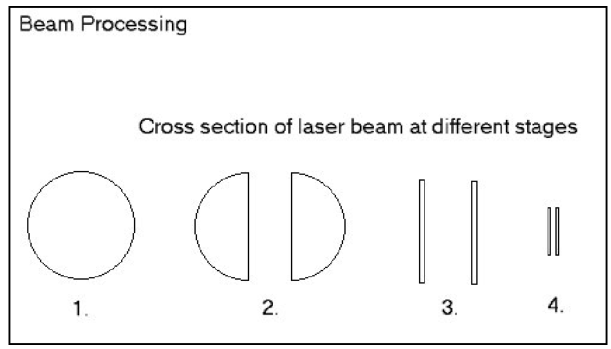

Figure 1

1. initial beam from the laser
2. beam after passing through the beam splitter
3. beam after passing through the shutter system
4. beam profile at the point where the inkjet droplets pass through the beam (i.e. after the beam has passed through the lens)

The inkjet droplets are fired through the laser beam just after the focal point, which gives rise to two signals (one from each of the two photodiodes). The photodiode output signal seen is due to the "shadow" cast by the inkjet droplet as it passes through the beam. The signal is proportional to the dimension of the droplet as determined by the system calibration. As the beam is processed to a very thin slit and the data is captured at a very high sampling rate, the droplet profile is effectively split into very thin slivers, which can be reconstructed in the software to give a profile of the droplet. From this profile it is then possible to calculate the volume of the droplet.

The signals from the two photodiodes occur with a small delay between them, as the droplet passes first through one beam and then through the next. It is from this delay and knowledge of the distance between the two beams that the droplet velocity maybe calculated. A schematic of the laser beam and print head arrangement is depicted in figure 2 below.

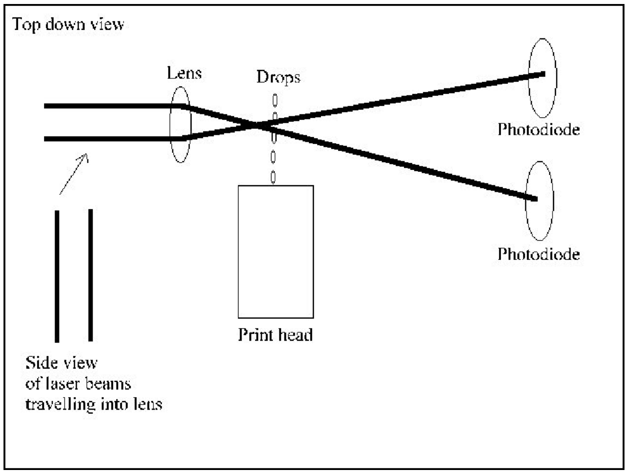

Figure 2

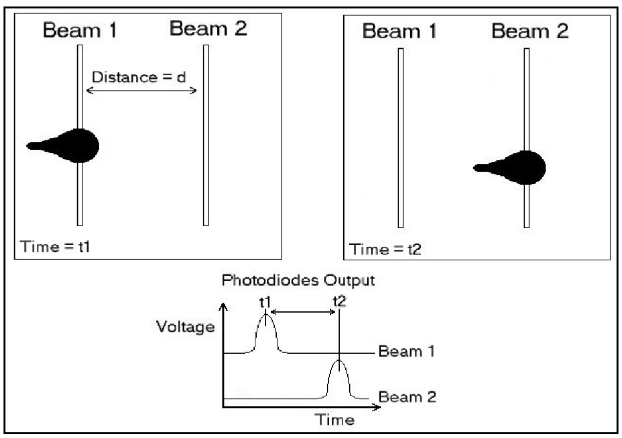

Figure 3

A 20MHz data acquisition board allows the capture of ~40 data points for a 40µm diameter (~33.5pL) droplet. Note: this is equivalent to a 10MHz data capture rate, as two channels are required to support the two photodiodes required for measurement of the droplet velocity. Figure 3 below illustrates the principle by which droplet velocity maybe measured.

Shown is a cross section of the drop as it passes through the two laser beams; passing through Beam 1 at time=t1 and then passing through Beam 2 at time=t2. The distance (d) is that between the centers of the two beams, which is calibrated in the initial set up (and maybe varied as required). The time of flight (t2-t1) is determined from the delay between the maximum due to the drop appearing in the output from Beam 1 and then in the output from Beam 2.

The velocity equation is then simply-

$$v = d/(t2-t1) \quad (1)$$

By the same theory it is also possible to calculate the velocity of any ink moiety other than the main drop (i.e. satellite, aerosol, etc.) and it should be noted that the velocities of these other components often vary significantly from that of the main drop. It is possible to vary the distance between the nozzle and the first beam and then also the distance between the two beams. Hence, the droplet may be characterized at any point along the entire trajectory and the velocity can be determined over a small distance or over the entire throw distance (distance from print head to substrate).

Example Experiments

In designing a reliable inkjet system, there are a wide range of operating conditions to consider. In most inkjet systems, to maintain the viability of the nozzles in a print head, there are a number of automated "housekeeping" processes that occur, without the user's knowledge. In defining the type and regularity with which these housekeeping processes must be performed there are two key parameters, these are "latency" and "de-cap time", which may be defined as follows-

Latency - the time a given nozzle may remain un-capped and not firing before the velocity of the first drop ejected is reduced by 20% from that of the steady state firing velocity.

De-cap time - the time a nozzle may remain un-capped and inactive before it is no longer possible to eject an inkjet droplet by firing the print head. (Note: subsequent firings may eventually produce a drop, but it is the absence of the first drop from the first firing that indicates the de-cap time has been exceeded).

The definitions of these two terms are highly reliant on measuring the properties of the "first drop out" of a print head. In the past this has proven difficult and has mainly been achieved by expensive high-speed camera techniques that allow the capture of an individual drop (the first one) but not subsequent drops. Also, indirect approximate measurements made with camera/strobe systems or analysis of printed images have been used.

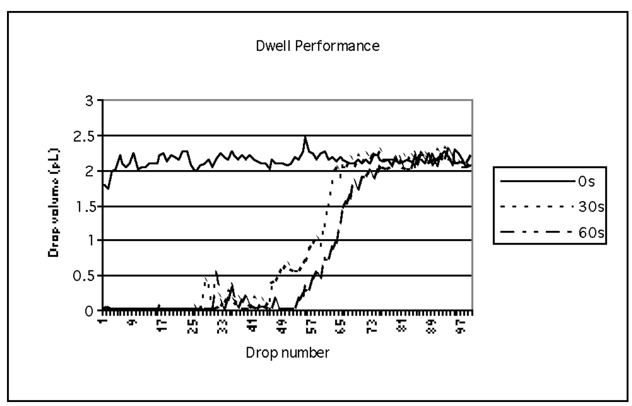

Figure 4

In order to define the maintenance algorithms for a given system, the Genie allows the synchronous start up of firing and data capture, such that the properties of the first droplet out of the print head (and subsequent droplets) maybe determined. Figure 4 below shows data for a print head that has been left idle and uncapped for varying periods of time. From this it is evident that if a nozzle is idle for more that 30seconds it is necessary to fire almost 80 drops before the system has recovered sufficiently to produce consistent droplets – with this type of information it is possible to determine how often the print head needs to spit and how many droplets should be spat.

A further important component in understanding the reliability of an inkjet system is determining the reproducibility of the droplet formation process. Genie allows a print head to be continuously fired for lifetime testing, with data collection triggered as the user desires throughout this testing. The data sets may then be compared to determine the performance effects seen as the ink supply is diminished and also measure the mean time before failure (MTBF) for the print head. In designing an inkjet cartridge or ink supply, it is important to achieve a constant back pressure through the life of the cartridge to keep the performance of the system constant. Experiments maybe conducted as part of lifetime testing to ensure that drop volume and velocity are not significantly altered as the ink level in the cartridge is depleted.

It is also possible to examine the deviation of drop velocity and volume within a data set, to determine how consistent and stable the ink performance is – this provides a guide to not only reliability but also print quality, see Figure 5 below.

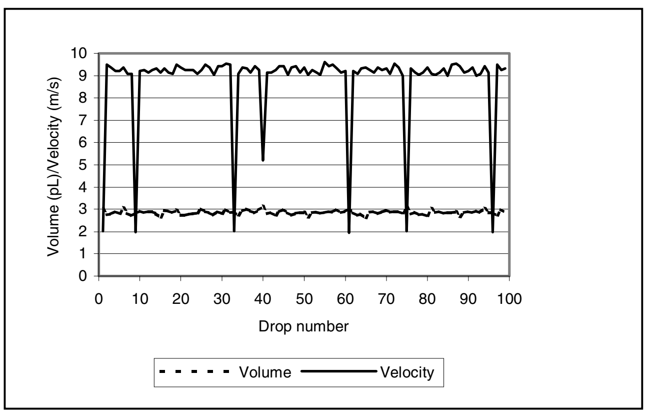

Figure 5

Matching ink chemistry to the correct print head driving conditions is key in designing an inkjet printing system. Seemingly unreliable ink formulations may suddenly perform reliably with only subtle changes in drive voltage, firing frequency or drive waveform. Also, with many modern printers supporting a number of different modes, the driving conditions can vary significantly so it is important to characterize a system across a broad range of conditions. Figure 6 below shows characteristic data for droplet velocity measured at a number of different drive voltages.

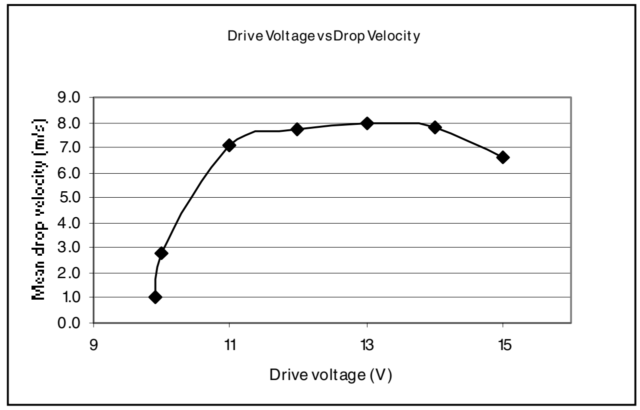

Figure 6

One final significant benefit in generating quantitative characteristic data over simple visualization is the aid to manufacturing of a product once the development is complete. All of the data generated during the development maybe used in defining accurate manufacturing specifications for the product based on simple numerical values rather than subjective interpretation of images.

Conclusion

A system has been developed that makes a significant step forward in quantifying inkjet performance. The key parameters of droplet volume and velocity maybe quantified for individual droplets in flight. A profile of the ink stream and drop break up is also generated. The driving conditions for the inkjet print head are flexible and maybe tuned to optimize performance.

The great importance of these measurements in producing better (more reliable and higher quality) products more rapidly than was possible with previously available techniques has been demonstrated.

References

1. Sung-Cheon Jung et al, IS&T NIP15, pg.18 (1999).
2. Christopher Evans et al, IS&T NIP15, pg.78 (1999).

Biography

James Fox became R&D Director of Xennia Technology Ltd on 1st March 2001, having been with Xennia for 4.5yrs. During this time he has been involved in the development of a number of break through "ink" products, gaining experience with all print head technologies. Through Xennia's development activities he became heavily involved in the production of a range of tools and instrumentation for the Inkjet Scientist, of which the Genie system described in his paper is now marketed by VisionJet Ltd, a wholly owned subsidiary of Xennia Technology Ltd.