Advances in technologies for Wide Web Single Pass Printing with piezoelectric Inkjet

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Abstract

In the past it has been extremely difficult to attain the required quality and reliability needed to achieve a viable wide array single pass inkjet system to satisfy the needs of the printing industry for label and billing applications. However it is now practical to form such a system by utilizing a combination of several novel technologies.

Printed inkjet quality has been achieved in the past by using a very fine pixel array requiring either a high nozzle density across the array or multi-passing techniques to fill in the gaps. The latter not being suitable for single pass applications, the industry has had to stack low nozzle density printheads to synthesize a higher density array. Unrestricted greyscale technology allows for images of apparent binary resolutions of about 1000 DPI to be created from medium resolution arrays. Shared Wall piezoelectric technology allows for the creation of such medium resolution arrays.

Reliability is the other critical factor. In the past this has usually been achieved by redundancy or regular maintenance of the printhead to ensure that the nozzles remain primed with an intact meniscus. Again the latter option is not practical for a single pass printer but recirculating the ink at the nozzle (throughflow technology) effectively provides continuous maintenance of the meniscus irrespective of printed duty cycle and so allows for interrupt free operation.

Incorporating shared wall operation, greyscale and the throughflow recirculation technologies together in a single printhead can give a physical nozzle density of 360 NPI an apparent binary resolution of nearly 1000 DPI when using 8 greylevels and be virtually maintenance free when printing.

Single Pass Requirements:

Over the past few years inkjet quality has been associated with the quoted ‘drops per inch’ (DPIs) of the printer and the “bigger is better” mentality has been applied. As a result of this, systems have been developed quoting higher and higher DPIs but only sometimes achieving better quality. The numbers have arisen from calculations based on printing with multiple passes and are often not representative of the actual printed DPI. Translating these numbers into single pass applications is neither practical nor useful. There is a need to look at what is actually required and the technologies available to achieve these.

Similarly in the past inkjet systems have been characterized by their relative lack of reliability compared to traditional printing processes. To make inkjet reliable it is often necessary to introduce regular maintenance or variable amounts of redundancy. The former of the two is not practical for single pass printing in a commercial environment and the latter often comes with a high financial or speed penalty.

Quick Analysis of Required Print Quality:

Typically the human eye of an average person can discern approximately 200 grey levels. Though discrimination of these levels is not linear, for the purpose of this paper it will be assumed that it is. Also at normal viewing distances (reading distances) the average eye can not resolve items separated by less than about 1/100 inch.

Firstly it is necessary to derive some kind of comparative relationship between DPIs of a binary printing system and those of a greyscale system. Consider a “super cell” pixel spacing of 100 DPI and subdivided into a square array of 200 binary pixels. This will produce 201 greylevels. It would be necessary to address binary pixels at 100 x $(200)^{½} \sim$ 1400 DPI to achieve similar results. However should there be a technology that could produce 200 different shades, or in other words effectively printing the whole “supper cell” in a single drop of variable size then it would only be necessary to print at 100DPI.

This relationship between greylevels, actual DPI and equivalent binary DPI is a useful working approximation. It should be noted that this relationship only holds when working beyond the limit of resolution. i.e. the actual drop spacing is less than 1/100 inch (100 DPI). Now for any actual DPI and number of grey levels it is possible to calculate the equivalent binary DPI to produce a similar print quality.

$$\text{Effective binary DPI} = \text{DPI x (GL)}^{½}$$

There is however a second consideration which has to be taken into account. When attempting to print a tone less than the smallest greylevel it is necessary to increase the spacing of these smallest drops. These drops now risk being resolvable as their spacing exceeds 1/100 inch. At 200 DPI a person would be unable to resolve drops at a halftone approximately ¼ of the lowest actual tone available from the printhead.

From the above it is possible to set the following two criteria for the design of a printing system where it is necessary to specify the number of greylevels available (GL) and drop pitch (DPI) on which they are to be printed. We can characterise these criterion as follows:

$$\text{Effective binary DPI} = \text{DPI x (GL)}^{½} > 1400$$

$$\text{Lowest smooth tint} = 1/\text{GL} * (100/\text{DPI})^2 < 0.5$$

These above two criteria will be used as the base requirements for a single pass system to achieve acceptable print quality for full tonal range images to be viewed at normal hand held reading distances.

For example; a combination of 360 DPI and 15 greylevels gives an effective binary DPI of about 1400 DPI and a lowest smooth tint of 0.5%. Such a combination would satisfy these two requirements.

The technologies now available to achieve this are as follows:

Greyscale Technology:

Greyscale technology allows for the creation of larger effective DPIs than the nozzle array's 'nozzles per inch' (NPI) that they are generated by. The larger the number of greylevels available the smaller the NPI has to be to achieve the same perceived DPI at the same viewing distance. The relationship between NPI, Greylevels and "effective binary DPI" has been show in the previous section. Smaller NPIs are generally easier to produce, take up less space and require less electronics to drive them.

There are two different commonly used ways of producing variable sized drops, or greyscale output. The first is where different sized drops are ejected by applying different forces for different periods of time to the piezoelectric material. This leads to drop sizes that are not necessarily linear in size increments. The need for constant drop velocity means that this technique is usually limited to a small number of different drop sizes of non-linear distribution.

The second method is called "multipulsing". In this method a succession of drops, referred to as droplets, are produced in very rapid succession such that the newly forming droplet emerges before it's predecessor has separated from the nozzle plate. The resultant drops are or nearly are linearly sized, quantized by the droplet size. Drop velocities are also implicitly more uniform. Figures 1a & 1b illustrate both the theory and actuality of such a method respectively.

Combining the droplets at the nozzle plate to form larger drops has several advantages over leaving them separate. Small drops are very susceptible to aerodynamic forces so landing accuracy of the larger drops is greater. Satellite drops and misting are a result of break off of the drop ligature. For a drop created out of 7 droplets there is only a single ligature, hence 1/7 of the satellites.

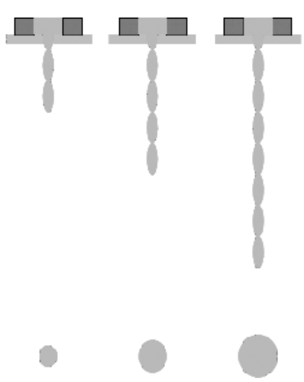

***Figure 1a**.Multipulse Drop Formation*

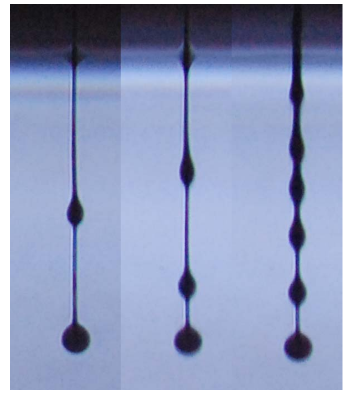

***Figure 1b**.Actual Drop Formation*

Using multipulse greyscale it is easily possible to create 15 different drop sizes of nearly linear volume, at generally uniform velocities. This needs to happen at very high frequencies. Other piezoelectric greyscale technologies generally do not offer these advantages.

Shared Wall Technology:

In a high density device, like an inkjet actuator, efficient conversion of electrical energy into fluid pressure is necessary. Piezoelectric operation in the shear mode benefits from a large actuator area contacting the liquid in the channel, so that adequate displacement is achieved. If the roof is the active piezoelectric component (roof mode) then the channel spacing must be relatively high to achieve the required contact area. In most cases this leads to single dimensional arrays with nozzle densities of little more than 50 nozzles per inch (NPI) for drop sizes of 30-40 pl (30-40 pl drop size is required to achieve full coverage on a 360x360 DPI image). Consequently this has led to the need for these arrays to be stacked 6 to 8 deep to achieve the required NPI/DPI.

The utilization of the walls between the channels as the active piezoelectric component (Shared Wall) has meant that the width of the roof can be reduced as the roof no longer needs to have a large contact area. This has allowed for higher density arrays to be created. It is often pointed out that the actuation of a single wall effects two channels. However, this effect is relatively easy to compensate for.

When building piezoelectric actuators there are potentially two modes of operation of the PZT. The first is called "direct mode". In this mode the electrical field applied across the PZT and the material either extends or contacts in this axis. The other axes react in the opposite sense so that overall volume is preserved. If the field is applied at right angles to the polling direction of the PZT then the material deforms like a parallelogram. This is know as "shear mode" operation. A key advantage of "shear mode" operation is that the life of the actuating structure is increased by a factor of about 1000 over "direct mode" operation. The difference between these two modes of operation is shown in Figure 2.

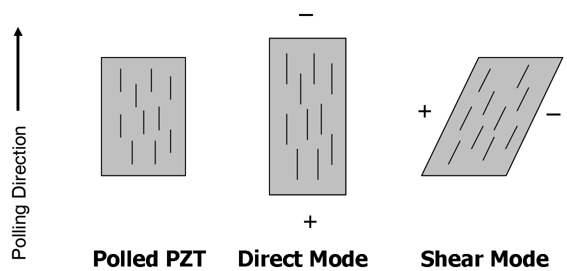

***Figure 2**. Different PZT operation modes for an applied field*

For a diagrammatic view of a shared wall architecture utilizing "sear mode" operation of the PZT material see Figure 3.

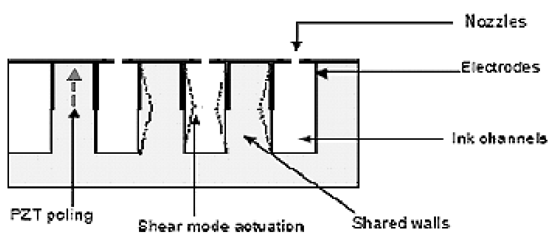

***Figure 3**. Shared Wall "Shear mode" Actuation*

Furthermore, shared wall operation also lends itself to acoustic firing. With roof mode operation the drop is ejected by physical ink displacement by deforming the roof, or any other part not common to two or more channels. The back pressure being produced by a restriction at the ink inlet end of the channel. With acoustic firing, a pressure wave is setup in the channel by flexing the shared wall. This pressure wave is reflected at the open end of the channel back to the nozzle. At this point a reinforcement pulse is added. This type of construction means that there is no need for a restriction at the input end of the channel, a feature that will be exploited in the throughflow technology described later.

A combination of acoustic firing and the shared wall actuator makes it relatively simple to achieve 150–180 NPI/DPI, approximately half what is required for single pass printing.

Reliability Analysis:

Piezoelectric drop-on-demand inkjet relies on the close control of the meniscus at the nozzle plate. For a long time the inability to control this meniscus has been an issue with respect to printer reliability. Poor control of the ink pressure in the channel or the occurrence of physical shock can lead to meniscus break down.

Rectified diffusion, the process by which gas comes out of solution due to reduced pressure and does not return under the equivalent positive pressure, can also be highly problematic. This pumping action causes small bubbles created in the active channel to build in size. These bubbles in turn act as damping in the channel and can lead to changes in jetting performance before completely the depriming the nozzle by destroying the meniscus [1]. When the meniscus has been destroyed it is necessary to draw ink back into the channel to remove the air and allow the meniscus to reform. Finally particulate contamination, from either side of the nozzle plate, can lead to a nozzle blockage.

Throughflow Technology:

Throughflow technology has been developed to address and solve the above reliability issues.

It allows the ink to pass directly across the inside of the nozzle plate giving continuous meniscus maintenance. As a result of this any depriming that occurs for any reason will have the meniscus restored almost immediately. Figure 4 shows the flow of ink passing through the active parts of the channels and directly across the nozzle orifices.

Figure 4 shows an example implementation of throughflow incorporating a single ink inlet and two outlets feeding two actuators to double the actual NPI of the printhead.

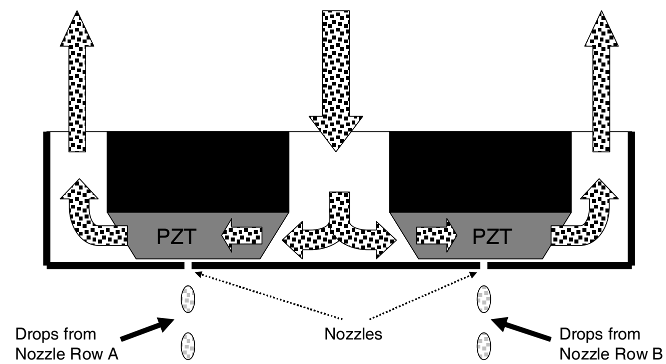

***Figure 4** Throughflow Ink Configuration.[Side View]*

Typically the flow volume is 10 times the maximum ejection volume so particulate matter and gas bubbles are quickly removed from the channel. The open ended channel used in conjunction with the acoustic firing technique (i.e. having no fluidic restriction) allows effective implementation of the throughflow technology.

There are throughflow technologies where the flow is much lower, as utilized by the Aprion printhead, which also give continuous meniscus maintenance.

Not all recirculating ink systems should be referred to as throughflow. Non throughflow systems typically recirculate the ink across the back of the channel and not the nozzle plate. This leaves a blind channel where ink is essentially static allowing for the accumulation of gas bubbles, particulate contaminants and provides little or no meniscus maintenance. It does allow for higher pigment loadings but suspensions can still be an issue as the channels are still static. Figure 5 shows an example of recirculation through the head but still leaving a blind channel.

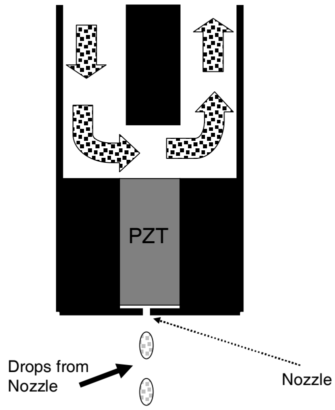

Figure 5. *Recirculating Ink Configuration with blind end.[Side View]*

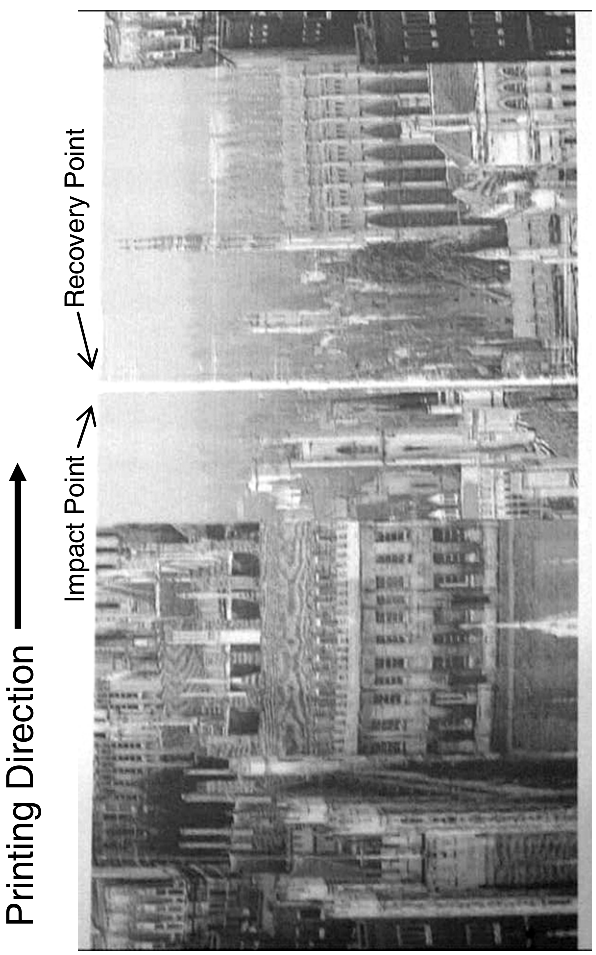

Figure 6.*Print showing auto-recovery of the meniscus on a print head utilizing throughflow technology after a physical impact.*

An example of the benefits of throughflow technology is shown in Figure 6 where the meniscus has been broken by a physical impact to the head (in this case the head was hit with a small rubber headed hammer) and has auto-recovered. Print speed was approximately 0.5m/s and was printed from the bottom of the picture to the top as shown. The impact was hard enough to deprime all the nozzles on the head instantly (note the sharp edge at the cut off). Recovery was completed for all channels within a few millimetres of print. The recovery is not synchronous, hence the slightly ragged appearance of print on the trailing end of the interruption.

Summary:

All the above three technologies, shared wall, grayscale and throughflow, can be combined together to make a truly commercially viable single pass printing system. Shared wall technology actuator printheads yields 180 NPI. The acoustic firing of the shared wall allows for a full throughflow system giving the required reliability. The throughflow technology leads to an easy doubling of the NPI. Finally multipulse greyscale provides the added effective resolution to give a binary equivalent of 1400 DPI.

Other requirements for single pass systems such as drop size consistency, landing accuracy and directional consistency are not effected by any of the above technologies either in isolation or in combinations.

Products such as the Xaar 1001 printhead, having been introduced in 2006, are now being built into products such as the Nilpeter Caslon narrow web press which is now being delivered to end user customers.

References

[1] Jos de Jong, Michel Versluis, Gerrit de Bruin, and Detlef Lohse, “Air entrapment in piezo-driven inkjet printheads” (Oc´e Technologies B.V., Venlo, The Netherlands, 2005).

Author Biography

Julian Bane received his BA in Computer Science from Cambridge University in 1983 and initially worked with David Kindersley on Typography research before moving into the digital print industry. Since 2004 he has worked as a Technology Specialist at Xaar PLC where he researches both new inkjet and imaging technologies. He has invented several inkjet specific imaging techniques, including optimal grayscale halftoning techniques. His new piezo actuator designs are now central to the next generation of high performance printheads.