Approaches to High Speed Inkjet Printing

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Abstract

Inkjet aspires to be the dominant technology in commercial printing. Current and future uses of inkjet in that printing market demand faster print frequencies and higher print speeds to achieve the desired throughput and productivity. Xaar is developing a range of technologies that enable high speed printing and exploring the limits of their suitability in specific applications.

One such technology uses recent advances in the exploitation of shared wall technology to enable the development of single cycle nozzle operation for shared wall devices. The elimination of the 3-cycle firing mechanism facilitates a threefold increase in print speed without a trade off in image quality. This print performance is a result of continued understanding of fundamental mechanisms associated with complete drop ejection. Printhead evaluation has shown thermal management, drop placement and reliability can meet the requirements with the new productivities.

An alternative technology uses standard printheads stacked together inline, printing in 3-cycle firing mode. For this configuration the print image is split accordingly between the printheads and thus the print speed can be increased by a factor equal to the number of printheads. Printhead stacking has been explored by increasing the stack up to seven printheads on an offset-press. The effectiveness of this configuration is evaluated as a function of firing frequency and substrate feed rate, offering important information that needs to be considered for high frequency integrated system design.

Introduction

Emerging digital printing technologies are favoured for their increased agility and efficiency when compared to many of the analogue printing processes. Already digital presses are available which demand capital costs that are lower than their analogue counterparts.

More significant however is the reduction in skill and resource necessary to operate well-engineered systems and the resulting predictability and low cost of operation and ownership. Typically inkjet devices are fabricated at the micro-scale, so that the digital print array is small and the digital press can be designed to occupy a reduced physical footprint. Space is also saved through the automation of maintenance cycles, for example nozzle plate wiping and recurrent (re-circulating) ink reconditioning, which alleviates need for areas in which manual cleaning and refurbishing operations can be carried out.

In recent years the software used in pre-press has been developed to find as much efficiency in the workflow as possible. Online access allows coincident working on a single product and key functionality automates common steps to reduce errors, reinforce quality standards and speed up preparation for production. While these advances have been applied to digital and analogue presses alike it is the print on demand (POD) markets where the digital press has had a significant impact.

The on-demand nature of the digital press has provided publishers with a number of advantages:

- Publications which are out of print can be made more easily available. Sales for individual titles may be low, but where cumulative sales may be significant.
- Titles that are expected to have large sales but a short sales life represent high profitability but also high risk owing to the danger of printing more copies than are necessary. POD allows risk to be minimised by forecasting low and using POD to print the difference.
- In certain "niche" markets publications may have a high retail price but limited sales opportunity. The publisher may be expected to keep these specialist titles in print even though the target market is almost saturated; making further conventional print runs uneconomic.
- Publications are easily printed in a variety of formats, e.g. larger fonts for those with vision impairment, personalised fonts and formats that suit individual needs.

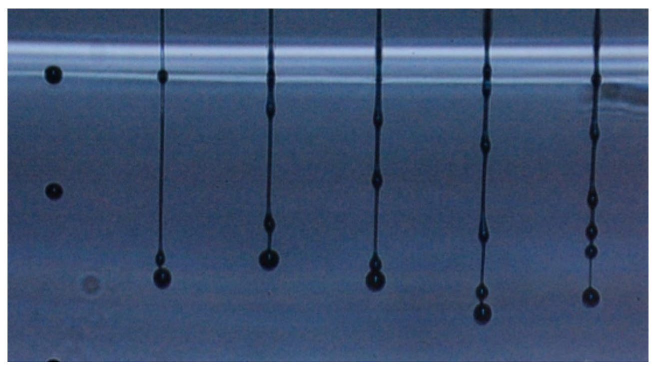

Figure 1 *Droplet ejection showing the drop formation of a single cycle greyscale shared wall Xaar 1001 actuator*

However, the maximum production throughput of the digital press is often significantly less than that, to which the user may be accustomed, thus opening opportunities for a digital printing technology capable of combining increased throughput with other key demands of industrial inkjet applications. This paper will discuss two different approaches to high speed inkjet printing as alternative methods to achieve this higher productivity; Type 3 mode of operation and ‘stacking’ printheads together.

High Speed Inkjet Printing

The Xaar 1001 is widely used in digital label press applications but linear speed is limited to below 0.5 ms^{-1}. This printhead is operated using a 3-cycle firing scheme which allows every nozzle in the channel array to be active (reference here) so providing a high native nozzle density but limits the maximum print speed. 3-cycle firing uses the displacement of a pair of walls to generate a

pressure (P) in the ink which causes ejection through a nozzle associated with the chamber between those walls. Advantageously, while the chambers associated with this cycle are operated and experience a pressure P, the chambers associated with the other two cycles experience a negative pressure of ½P which act to stress but not damage the fluid meniscus in those non-printing nozzles.
Actually, Xaar also uses an acoustic firing technique in which the first wall pair move to produce a negative pressure (-p) which causes a pressure wave to flow into that chamber from the connecting ink manifold. Upon arrival at the nozzle this wave delivers a positive pressure (p) which is superimposed with pressure (P). This can mean that the non-printing nozzles can also experience positive pressures of ½P which again the nozzle meniscus must endure.

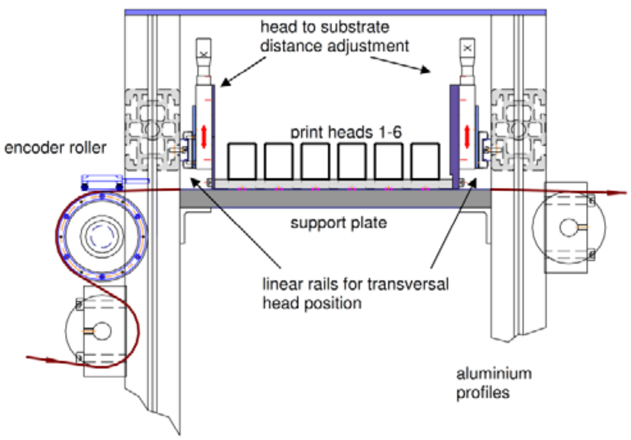

Figure 2 *Schematic layout of the printer incorporating a stack of 6 1001 printheads in a monochrome digital web press*

The need to sequentially fire nozzles according to this 3-cycle strategy acts to erode the high native firing frequency and limits the print speed. An obvious approach to increase productivity is the stacking of these printheads such that the substrate can be run faster and with the additional heads maintaining the ability to print full coverage. Figure 2 shows an example of this printer layout. The image to be printed must be split into the sections relevant to each printhead and the data transmitted accordingly. Theoretically this means that the print speed can be increased by a factor equal to the number of printheads.
The conceptual reel-to-reel printer (figure 2) has been designed to function as a reference substrate transport and is engineered to provide an extremely stable structure. This 6 head machine is capable of monochrome printing 360x360 dpi images at substrate speeds exceeding 2.5 ms^{-1}, although more modest arrangements using fewer heads in the stack have also been investigated.

This stacking method does offer, for some applications, a viable means of increasing the print speeds and since some configurations can use standard printhead products this does provide an early opportunity to address certain market sectors.
There are drawbacks however, and a number of challenges which may restrict wider adoption of stacked configurations. The complexity of this type of machine is high with the printhead stack demanding large or multiple drivers and peripherals ink and maintenance systems. Alone the capital cost of the number of printheads required to populate the stack could represent an unattractive proportion of the build cost. Further it is likely the additional effort necessary to assemble, configure and align the stacked arrangement is not inconsequential, especially where the printer OEM aims to compete in markets which are familiar with the modern offset litho press.

Another consideration is the potential size of the print area and the technical challenges for the alignment of drops in the image. The substrate position must be precisely controlled across its width, it position in time for the length of the printing area as well as its vertical location. While this may be realised in a reference machine the cost implication for the development and manufacture of a commercial printing machine may be substantial. An alternative printer embodiment, which might employ a printhead stack, is that which uses a rotating drum which is potentially more easily controlled (print path, position and height) to receive ink drops to the correct locations. A preferred embodiment of this type of printer is where the ink is printed onto the rotating drum and then transferred to the substrate which provides the opportunity to deposit an ink film having a thin and well controlled thickness. A key challenge is the transfer of the ink without residue remaining on the drum which Xaar has described in a recent patent [2].

Single Cycle

Several different methods to improve the productivity of shared wall actuators have been proposed previously. For example, putting a nozzle in every alternate channel (avoiding the sharing

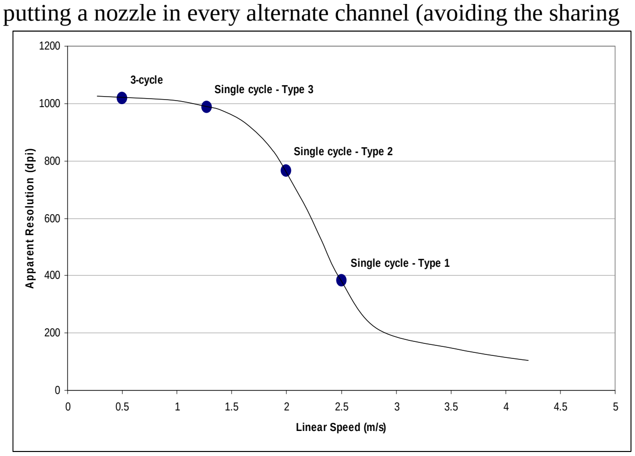

Figure 3 *Print performance shown as an apparent resolution against linear speed in a single pass*

of walls reduces the operating constraint) allows operation in a single cycle mode. Elimination of the 3-cycle mode immediately provides for threefold increase in available print speed but the loss of alternate nozzles reduces the printhead productivity by 50%, to just x1.5 the original. In single pass printing applications this would require the stacking of a second head to maintain print resolution and the limitations of this type of approach were discussed earlier.

Xaar presented a paper at NIP25 Digital Fabrication 2009 [1] which described different mechanisms to improve this throughput; Types 1, 2 & 3. Illustrated in Figure 3 is the range of linear print speeds and resolutions provided by these technologies.

In this section we will focus on the design and operation of the Type 3 printhead which remains capable of image reproduction having an apparent resolution of 1080 dpi (8 grey levels addressing a 360x360 dpi pixel grid) but is able to print at substrate speeds up to 1.27 ms^{-1}.

The single cycle mode of operation utilised in the Type 3 printhead exploits the fundamental properties of Xaar's shared wall actuator. The act of moving one wall of the actuator creates a pressure change in both adjoining channels. Careful timing of the wall movements can generate sub-drop ejection from both channels separated by a phase angle of 180º. For a sub-drop frequency of 200 kHz this results in delay of approximately 2.5 µs between the phases of sub-drop ejection. If this technique is used to print a straight line on the substrate then a small landing error (in this case approx. 1/10th of the pixel) will occur. If necessary subtle changes to the waveform can be used to compensate for this defect by increasing the velocity of drops ejected from the second phase.

The drive waveforms must address the sub-drop pattern demanded in the image but are bound by the synchronicity inherent in the shared wall structure. This results in a relatively complex waveform definition which requires additional manipulation of the image at a convenient location in the data path. The result is impressive with each channel able to independently eject any number of sub-drops giving rise to full greyscale operation (8 grey levels 360 dpi). Figure 4 shows an image printed with a printhead configured in this mode.

Figure 4 *Close up view of a monochrome image printed at 1.27 ms^{-1} using the Type 3 head*

Consideration of only the printhead operation is not sufficient to achieve satisfactory system performance. The system operates with a sub-drop frequency of near to 200 kHz (equivalent to a pixel frequency near to 20 kHz) which results in higher power consumption and unavoidably the generation of excess energy in the form of heat in the actuator and its electronic driver. If consistent and reliable performance of the device is to be maintained thermal management must be effective. Already Xaar employs a through-flow ink system that is used to thermally manage the actuator and actuator driver. The Type 3 printhead contains an extension to the fluid path and a more efficient thermal conduit such that the additional heat generated in the driver is removed. In the prototype shown in figure 5 this additional path employs a new circuit providing water at a rate of 300ml/min., although it is anticipated the printing fluid could also be used as the coolant with appropriate modification of the external ink system.

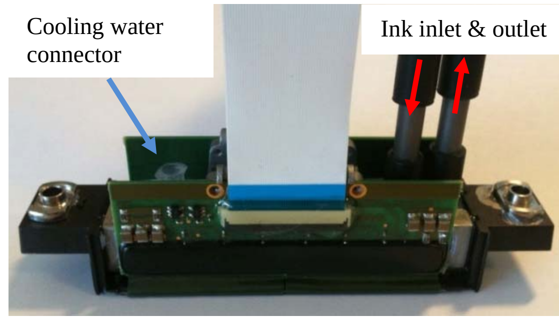

Figure 5 *A photograph of the Type 3 printhead.*

The capability of the Type 3 printhead represents a very significant technological development for the Xaar product family and its users. Advantageously, this new technology relies in many features of the established base platform of shear mode actuation, shared wall structure and greyscale droplet ejection stimulated by the use of longitudinal acoustic pressure waves. Much of the hardware is substantially the same as the parent 1001 printhead so that the risk associated with its adoption in to new products might be small.

Actually this step change in productivity could present many further challenges to the development of the print system; some of which are described in the next section. Experience suggests challenges are larger barriers to successful printer (or print process) development that might at first be anticipated.

Control of High Speed Inkjets

While the systems described in this paper allow increases in productivity higher press speeds can result in degradation of image quality as the placement of drops becomes less accurate. The system becomes more sensitive to variation in the time of flight of the inkjet drop which can differ for a number of reasons. Drops containing different volumes (number of sub-drops) will have different rates of deceleration due to air drag or differences in their trajectory arising from the influence of aerodynamic turbulence. Small non-uniformities in the materials or manufacturing of the actuator can have significant impact on the jetting mechanism; and thermal variation where the printing array across the actuator array see differing print duty changing the properties of the ink ligature and hence time that the ligature acts to decelerate the evolving drop volume.

Steps can be taken to minimise these and in the previous section certain improvements to the thermal control have already been discussed. Similarly it is possible to counter known variations in drop velocities with the modification of the ejection time of the drop, so that with reference to the centre of a given pixel drop volumes that are slow are ejected earlier and fast drops later. This can be particularly useful in certain situations, e.g. where a nozzle has been idle for some time it will contain little residual energy compared to those which have been recently active. A form of pre-pulse [3] can be applied to the waveform addressing the idle nozzle to provide additional energy to the first drops ejected. These methods are useful where the velocity variation of a drop can be predicted and where the system can be configured to adapt.

To reduce the effect of less predictable errors the system must be developed to exhibit a strong level of immunity. With this intent reducing the time of flight of the drop is a useful way to control the error associated with the drop landing. Xaar's printhead products, which use its 3-cycle firing technology, are configured to have a nominal drop velocity of 6 ms^{-1} since further increases in the generated channel pressures result in negative half pressures (refer to section Approaches to High Speed Inkjet Printing) which can increase the tendency for nozzle failure as a result of loss of control of the ink meniscus in the nozzle. In extreme cases this can cause the ingestion of air causing reduction of drop velocity or even a full de-priming of the nozzle or channel. It is a significant advantage that the single cycle mode of operation reduces this effect so that drop velocity can be increased as a means of maintaining image quality and the Type 3 printhead can reliably eject drops in excess of 15 ms^{-1}. However, ejection at high velocity can cause a large volume of ink mist as a result of the formation of a long ink drop ligature which can break into a number of small ink drops that can collect to impair image quality or the operation of the printer.

Often it is necessary to modify the formulation of the ink to improve its rheological characteristics and better control the drop formation and ligature break-up. We have developed new knowledge in this field and use tools to aid the reformulation of inkjet inks. The graph in Figure 6 shows improvement made to the print performance of an ink fluid with changes to its formulation

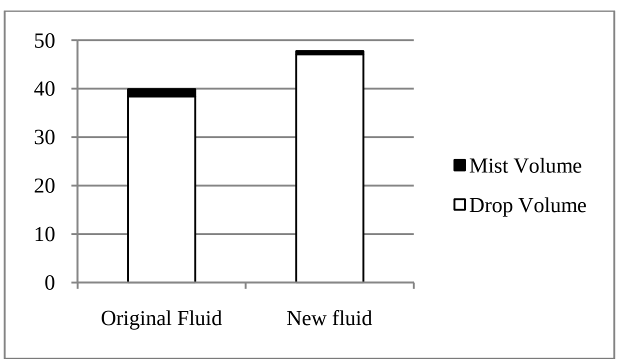

***Figure 6** Comparison of the 7 dpd drop and mist volumes (pl) at a constant drop velocity of 6 ms^{-1}*

This demonstrates an example of the way in which the performance of high speed inkjet systems can benefit from new knowledge that has been developed in relation to the rheology of fluids and inks. Advanced and developing techniques allow fluid formulators visibility of many of the rheological parameters which are closely associated with the conditions founds in the inkjet jetting process.

Conclusions

Market demands for the high speed digital press are strong and new emerging technologies will continue to lower previous barriers to adoption. The capability of the printhead is of primary importance and new developments like those described suggest drop-on-demand inkjet will be well positioned in the race for wider adoption and replacement of some of the traditional analogue technologies.

Increasingly the performance of the printing system is reliant upon the development and capability of compatible fluids and the peripheral systems. The generation of new knowledge in these areas is equally valuable where the print system is to exhibit or maintain levels of quality and reliability that compliment its new found productivity. System developers will find all of these new technologies an attractive proposition for an increasing number of market sectors.

Wider dominance of drop-on-demand inkjet in the commercial print market carries with it a new set of challenges. Many of the fundamental technologies can be extended to align well against those new requirements so that the future for drop-on-demand inkjet remains undeniably fertile.

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[2] Harvey R., *US Patent no. 2008223240* Method of Printing.

[3] Temple S., *US Patent no. 6629740*, Constant Energy Pulse.

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Author Biography

Paul Drury is Xaar's Technology Manager, heading the Technology team which undertakes the groups' fundamental research effort and leads early stage new product development activities. He hold a B.Eng. (Hons.) in Engineering and Engineering Systems from Portsmouth University and is named inventor on more than 30 patents in the inkjet field. He joined Xaar in 1997 as part of the engineering team which first led Xaar in the development of its own inkjet products. Subsequent roles saw him managing relationships with key development partners and industry suppliers in the pursuit of wide array technologies and greyscale products.