# Function and Performance of a Shear Mode Piezo Printhead

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## Abstract

In comparison to other work principles piezo printheads have outstanding features like low power consumption, high lifetime and high firing frequency. Modular Ink Technology is producing a variety of different "shear mode / shared wall" piezo printheads, based on the technology development of Xaar, Cambridge (UK). A detailed understanding of the functionality is important to find the optimum work point of the printhead. For this purpose, the impact of the work parameters on the functionality of the printhead must be studied.

In this paper the function principle and the design of the shear mode printhead are described. Special emphasis is directed to the shared wall principle, the pressure wave propagation in the channel, the printhead tilt angle, firing sequence and droplet formation. Furthermore, the correlation between performance parameters and drive conditions are discussed. As an example, the influence of the drive pulse amplitude and of the firing frequency on the droplet velocity, volume and ejection stability are presented. Moreover, the interaction of physico-chemical ink parameters like viscosity, surface tension, and temperature with the performance are discussed.

## Introduction

For the generation of an inkjet there is a variety of actuation principles each of which has gained its market share. Figure 1 illustrates various classes of important construction types. At bottom right is the shear mode piezo inkjet class, which is now further discussed, since the technology based on the "shear mode / shared wall" principle developed by Xaar[1,2] belongs to this class. The "shear mode / shared wall" principle is succesfully utilized in the PiezoJet™ printheads of Modular Ink Technology, a company which belongs to Nu-kote International Inc.

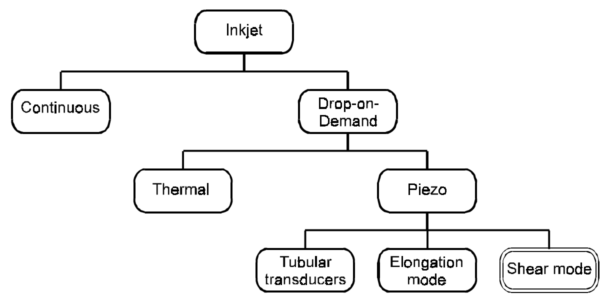


*Figure 1. Inkjet actuator construction principles*

The key for the actuation is the shear motion of the PZT, a piezo-ceramic material, as illustrated with an actuator wall in Figure 2. The material has a permanent polarization in z direction. If an electric field is applied in x direction, e.g. by two parallel electrodes along the wall, then a shear motion is obtained with y direction as the shear axis. This effect can be used to increase or to decrease the volume of ink in an actuator channel. In the following, the actuator and its function are described.

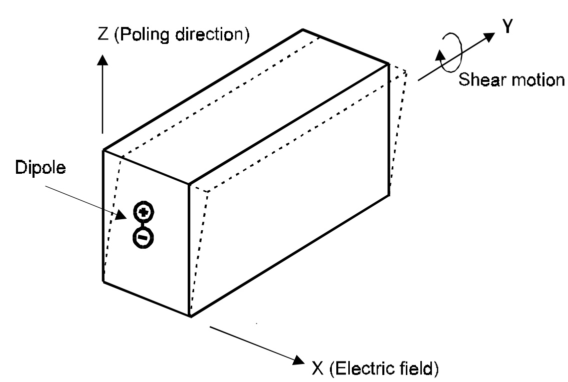


*Figure 2. Shear mode actuation of PZT by an external electric field*

## Printhead components

The basic components of a printhead (Figure 3) are the actuator and the driver chip. The actuator itself is built of a channeled base and a cover plate, both of PZT. The channels are filled with ink, and they are surrounded by the PZT of base and cover plate and by the nozzle plate at the front side. Each channel has one nozzle, through which the inkjet passes.

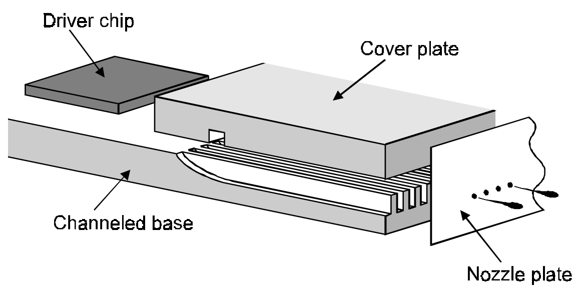


*Figure 3. Basic printhead components*

The cross-section of the actuator parallel to the channels is shown in Figure 4. With this prospective, the ink path can be followed from the inlet, going in the manifold and in the channels. The metal layers on the upper half of the walls are used as electrodes to generate the electric field which leads to the shear motion.

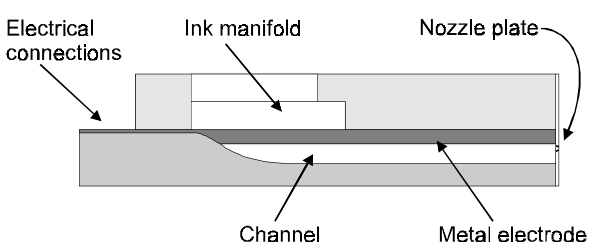


*Figure 4. Cross-section of the actuator parallel to the channels*

## Drop generation

The motion of the walls takes place as illustrated in Figure 5 which is a cross-section of the actuator parallel to the nozzle plate. The two electrodes belonging to one channel have a common electrical connection to the outside world. An efficient drop generation starts with a volume increase in the channel. This is achieved by means of electric fields which have opposite directions to each other. A glue layer keeps the top of the walls in their position so that the largest motion is carried out approximately at half of the wall height. Then the potentials on the electrodes are changed so that electric fields in the reverse direction are obtained. This results in a volume decrease in the channel and the ejection of a droplet. The final step is to go back to zero voltage with no electric field, no shear mode deflection, and the default channel volume. No other wall than those of fired channels may move, that means electric fields should only exist in walls of fired channels.

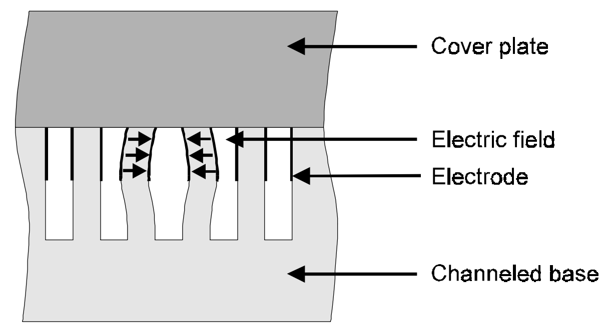


*Figure 5. Usage of electric fields and shear motion for drop generation*

The volume increase and decrease results in pressure waves, and the acoustic wave propagation must be taken into account for the drop generation[3,4]. Acoustic waves go forth and back, with velocities lower than in bulk ink because of the compliance of the walls. At the time point of the volume decrease, a positive pressure wave at the nozzle causes the ink ejection out of the nozzle. A backward going wave is reflected from the nozzle, with a magnitude depending on the nozzle reflection coefficient $R_N$. Typically $R_N$ is negative in order to obtain an adequate ink drop volume. Since the reflection coefficient at the manifold end $R_M$ is -1, in the following period a positive wave supplies ink into the channel to replace the ejected drop volume. Hence, acoustic wave propagation plays a role for the drop ejection and for the refill. Drive pulses are designed so that these effects are utilized. In addition, for the pressure wave propagation in many channels, a modal analysis has been carried out[5].

## Phase firing

With the "shear mode / shared wall" construction principle, at maximum only every second channel can be fired at a time, due to the motion of neighbouring walls in opposite directions. Moreover, since one wall of the adjacent channels is in motion, there is a probability for accidental droplets. In order to reduce this tendency, only every third channel is fired[4]. By this, only one wall of a neighbouring channel is moving.

Printing a vertical line without dot placement errors seems to be a problem, due to the different firing time points of the single phases. However, this can be solved e.g. by means of staggered nozzles, or alternatively, by tilting the printhead as shown in Figure 6. In the Figure, a carriage motion from left to right and a firing towards the image plane are assumed. A crosspoint of the grid represents the center of a pixel. The nozzles of the printhead are aligned along the tilted line. Phase A coincides with the raster and is firing. After a time, due to the carriage motion, phase B is at the right point to fire, and phase C follows in the same way. The three-phase firing at a given frequency, the nozzle distance,

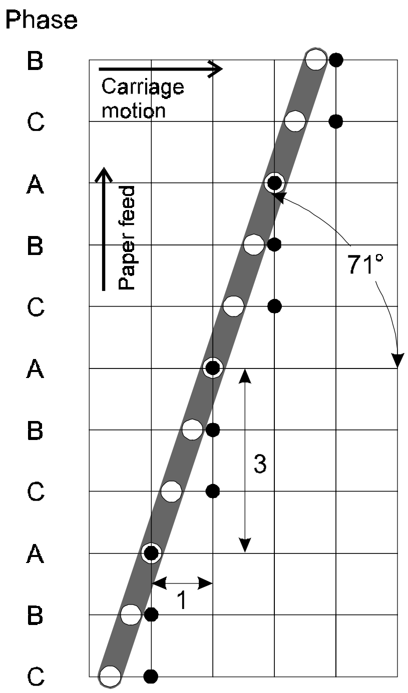


*Figure 6. Tilting the printhead for a given resolution*

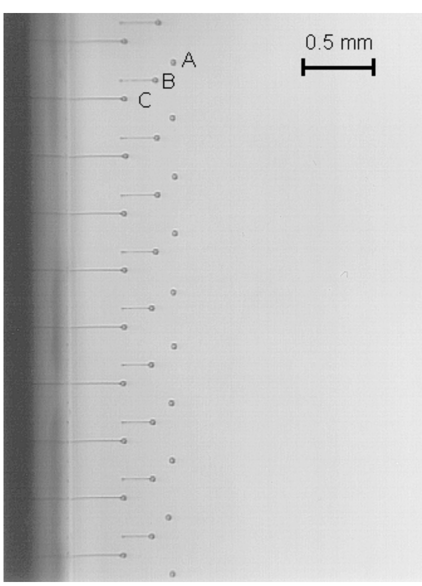


*Figure 7. Series of inkjets*

the tilt angle and a corresponding carriage velocity form a set of interrelated parameters which determine a horizontal and vertical resolution. The shown tilt angle of 1/3 is used in 200 dpi printheads. By the variation of the tilt angle, the vertical resolution can be adjusted differently, e.g. 360 dpi resolution is obtained with the 5/3 ratio. This is discussed in more detail by Kretschmer[6].

Figure 7 represents a series of inkjets from a 200 dpi printhead. Each inkjet comes out of a nozzle and forms a liquid column which separates after some 50 µs from the liquid in the channel and moves towards the print media. By surface tension, the column tends to contract to a spherical shape, and a single drop is formed. The three-phase firing is also visible, phase A being at the front and phase B and C coming later.

## Printhead performance and drive conditions

The relationship of the work conditions and the performance parameters must be known to find a suitable work point for the printhead. As a first example, the typical

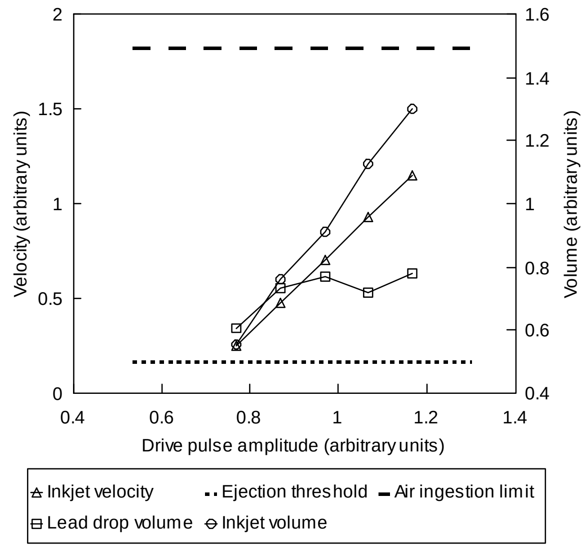


*Figure 8. Inkjet volume, lead drop volume and velocity as a function of the drive pulse amplitude*

linear relationship between the drive pulse amplitude and inkjet velocity and volume of a 360 dpi printhead is illustrated in Figure 8. A lower limit for the amplitude is the ejection threshold to overcome the surface tension forces by which the inkjet is kept back in the channel. At low velocity, the volume of the leading drop and the overall inkjet volume are identical. With increased velocity, satellite droplets, i.e. small droplets behind the leading drop, remain at the rear side of the column, and the lead drop volume deviates from the proportionality. The drive pulse amplitude can further be increased, until the air ingestion limit is reached at high amplitudes and corresponding high velocities. Stable firing is given at appropriate distances from the lower and upper limits.

Apart from the drive pulse amplitude and other parameters, also the firing frequency influences the inkjet velocity and volume. Variations of the firing frequency alter the history of replenishment, and depending on the remaining liquid motion from the previous ejection, the velocity of the following inkjet has different values. Using a bipolar pulse, i.e. a pulse which causes an expansion and a compression of the channel, with optimized pulse widths, velocity and volume can be kept within certain tolerances at firing frequencies up to 8 kHz with the present printhead design. By this, drop placement errors and variations in the optical density are avoided.

The physico-chemical parameters of the ink like viscosity and surface tension should also be taken into account since they have an impact on the inkjet formation. For typical liquids these parameters decrease with temperature, and it must be made sure that the printhead is working in the given temperature range. In order to prevent other influences, this can be investigated by measurements on specially adjusted ink samples at room temperature. Using such ink samples with different surface tensions, the obtained performance does not show significant changes in the measured range between 20 mN/m and 50 mN/m. Since the surface tension of a standard ink only changes by 5% between 10 ºC and 40 ºC ambient temperature, the inkjet firing is not significantly affected by surface tension changes.

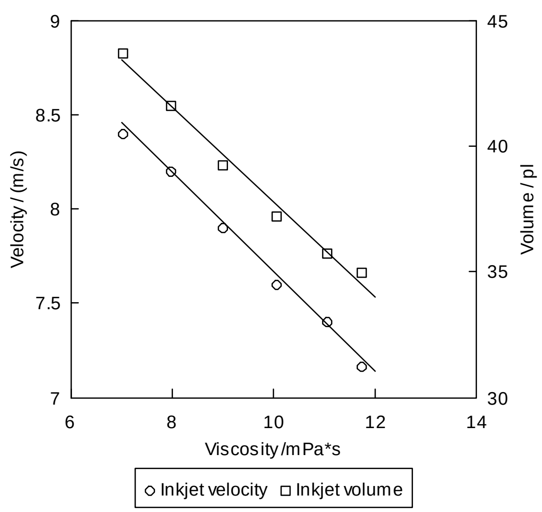


*Figure 9. Inkjet velocity and volume as a function of the ink viscosity*

In the same way, test liquids can be used to study the influence of the viscosity on the printhead performance at room temperature. The result is shown in Figure 9. With increasing viscosity of the liquid, inkjet volume and velocity decrease significantly. Moreover, the viscosities of typical liquids vary to a great extent in the temperature

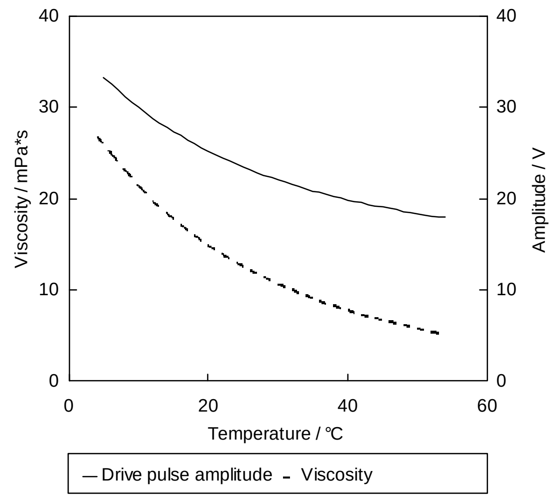


*Figure 10. Ink viscosity (dashed curve) and drive pulse amplitude (solid curve) as a function of the temperature*

range mentioned above. This is shown in Figure 10. As a consequence, a measure must be taken to keep the drive conditions for the printhead constant.

One possibility to obtain constant velocity and volume for the inkjets is to keep the temperature of ink and printhead constant. However, a temperature control might be costly and difficult to implement in a printer carriage. As a practical alternative, a temperature compensation in the printhead can be designed so that within a temperature range a constant velocity is obtained. This is achieved by adjusting the drive pulse amplitude as described above. Figure 10 shows the drive pulse amplitude for a 360 dpi printhead which is necessary to compensate for the viscosity change of the ink due to temperature variations. In the printhead, the temperature of the actuator is measured by a sensor, and using the sensor signal, the appropriate drive pulse amplitude is determined and adjusted by an electric circuit for a constant velocity.

## Conclusions

As a user of the "shear mode / shared wall" concept, Modular Ink Technology has designed its products to master and to take advantage of Xaar's technology. Additionally, provisions are made in the printheads to maintain the efficiency under various environmental and driving conditions as discussed in the paper, like changes in viscosity, temperature, firing frequency and others. With this, the printheads get the properties to make them suitable for a wide range of applications, from ticketing, labelling to wide format printing.

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# Errata

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page 151, The previous affiliation is now

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