Design Parameters of a Shear Mode Piezo Printhead for a Given Resolution

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Abstract

Due to the function principles, the selection of possible resolutions of bubble-jet and piezo printheads is restricted. In the case of the "shear mode / shared wall" piezo printhead, there is the limitation that not all channels can be fired at the same time. Moreover, each resolution requires a specified drop volume in order to obtain the appropriate optical density on the print media.

In this paper, the interdependence of print resolution, printhead tilt angle, carriage speed, and firing frequency is explained. It is also shown that a great variety of resolutions and print modes can be adjusted, despite the limitations mentioned above. Furthermore, possible changes of the geometrical design to vary the performance parameters as drop speed and mass are discussed. Based on this knowledge it is possible to obtain an optimal combination of resolution and drop volume, if also the ink/paper interaction is known.

Introduction

More and more drop on demand inkjet printheads enter the market. Different types of bubble-jet pens and piezo heads are existing. Each system has its own advantages and drawbacks, but some principles are valid for all of them. The major players in this field have their own technologies. HP, Canon, Lexmark and Olivetti are concentrating on the bubble-jet principle. Epson and Tektronix use different types of piezo products. Modular Ink Technology (MIT) entered the circle of printhead manufacturers using the Xaar "shear mode / shared wall" principle. The MIT products are called PiezoJet™.

Tilted printhead

The basic description of the pen geometry and the firing sequence has been given in the previous paper of Beurer[1]. It was shown that the printhead has to be fired in several groups. The reason is that neighbouring channels share the same wall. This seems to be a disadvantage because the firing of the nozzles has to be synchronised to these groups. Therefore a comparison with other printheads is interesting.

	Bubble-jet	Piezo	PiezoJet™
Energy per drop	10 ... 60 µJ	1 ... 6 µJ	0.2 ... 1.2 µJ
Nozzle pitch	300 ... 360 dpi	90...180 dpi	185 dpi
Print resolution	600 ... 720 dpi	720 ... 1440 dpi	200 ... 720 dpi

Table 1. Comparison of drop on demand inkjet technologies

In Table 1 the necessary input energies per firing, nozzle pitches and print resolutions of different printheads are compared. The values stand for typical representatives of the groups. It is obvious that the bubble-jet technology needs a much higher energy per drop than the piezo designs. Moreover, there is a high difference in power consumption if only several droplets are fired or if the printhead is printing black areas. This difference would cause a variation of the dissipation energy for the thin-film resistors and therefore result in a poor stabilisation of the droplet ejection. The reason is the dependence of voltage drop across the commons[2] on the number of driven heating elements. In order to solve this problem without using a separate common line for each resistor, it is necessary to multiplex the printhead. This means the heating elements are also divided into several groups, so that only a few resistors have to be fired at the same time.

The time which is necessary for multiplexing the nozzles has to be compensated, otherwise a dot displacement on the paper is visible.

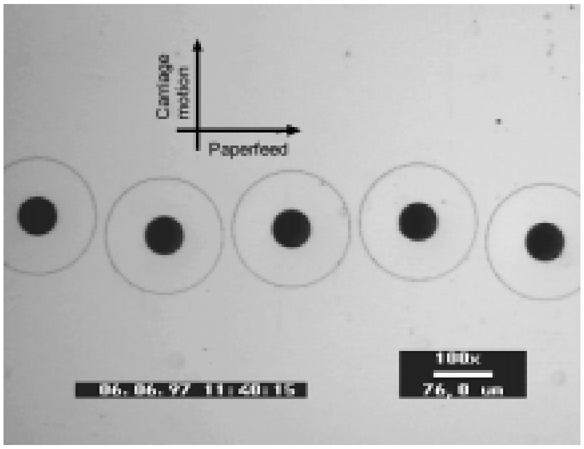

Figure 1. Staggered nozzles of printhead "X"

In order to compensate the time delay between the firing of neighbouring nozzles, manufacturer "X" uses staggered nozzles[3]. This is shown in Figure 1. The staggering distance of the nozzles together with the motion of the printhead relative to the paper compensates the multiplexing time delay. Thus, carriage speed, staggering distance and multiplex time are correlated and have to be adjusted. It is also clear that the firing frequency and the horizontal resolution are connected to the carriage speed. If one of these parameters is changed (e.g. the carriage speed) the whole balance is disturbed which results in a dot displacement.

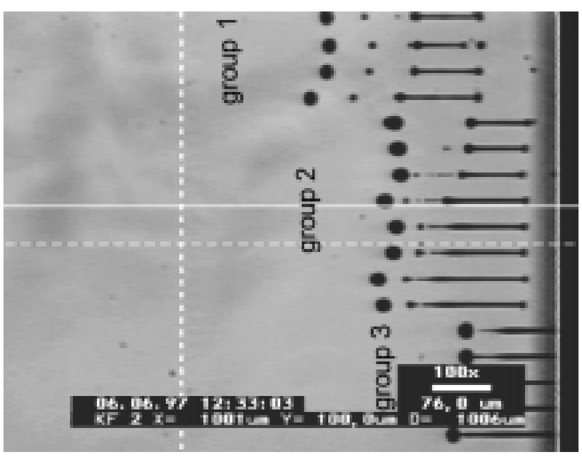

Figure 2. Printhead "Y" group firing. Eight Droplets belong to the same group.

Manufacturer "Y" has a different approach. In the older printheads the line of nozzles is divided into different groups as shown in Figure 2. These groups are multiplexed. In order to compensate for the time delay between the groups, "Y" tilted the printhead slightly against the movement direction. The result is a compensation of the average dot position. The disadvantage of this principle is that a dot displacement within a group is visible in printing vertical lines. Another drawback is the influence of crosstalk. The firing of one channel influences the drop ejection of the neighbouring channels. This produces different print qualities for different print patterns. Both reasons caused "Y" to use a different distribution of the nozzles to the groups[4]. This principle is shown in Figure 3. Neighbouring channels belong to different groups. Only every sixteenth nozzle is fired at the same time. The multiplex time is compensated by a tilt angle of a ratio 1/16. This results in 86.4° against horizontal for the new printhead of "Y".

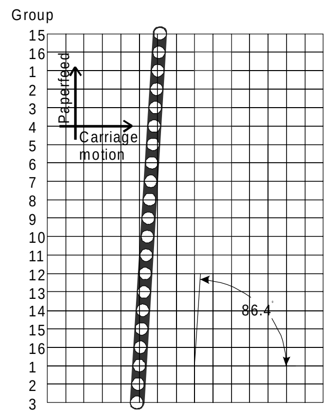

Figure 3. Tilt angle of the new "Y" printhead

A similar solution is used for the MIT printhead. The nozzles of the PiezoJet™ printhead are distributed to 3 groups, called A, B and C phase. In order to compensate for the time delay between these phases, the printhead is also tilted, but much more than the new "Y" head.

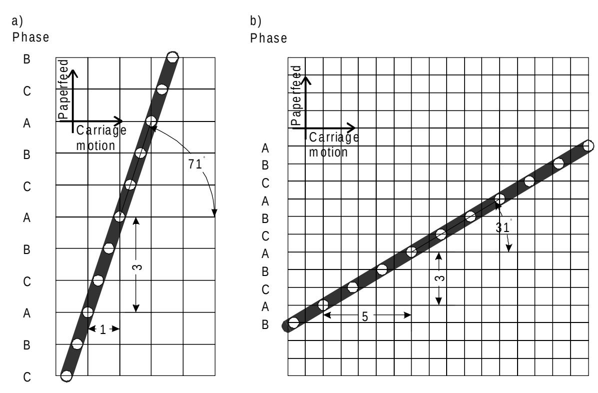

Figure 4. a) 200 dpi and b) 360 dpi tilt angles of MIT printheads

At MIT, presently 200 dpi and 360 dpi printheads are produced. The difference between both types is the drop volume and the tilt angle. Figure 4 shows the tilted printhead against the background of the print grid. At a tilt angle of 31° from horizontal position, a resolution of 360 dpi is obtained, while 71° result in a print resolution of 200 dpi[5]. In both cases the printhead has the same pitch, i.e. distance between nozzles. The multiplexing of the printhead is compensated if the relative velocity between the printhead and the substrate is adjusted to the firing frequency.

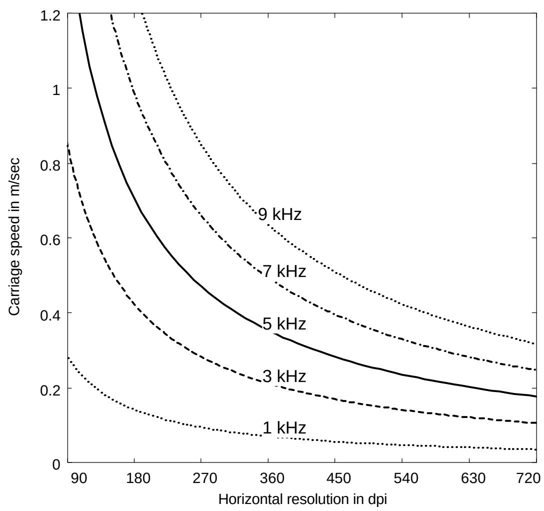

Figure 5. Carriage speed versus horizontal resolution for different firing frequencies

In general, different tilt angles for the printhead are possible. The allowed ratios for the tilt are described by:

$$mod\left(\frac{nh}{nv}\right) \neq 0$$

where *nh* is the number of horizontal resolution units and *nv* is the number of phases (in our case *nv* = 3). A tilt ratio of 1/3 and 5/3 was used for the 200 dpi and 360 dpi heads respectively. A ratio of 3/3 is not possible because in this case all nozzles of the printhead would be in printing position simultaneously. Therefore, one would have to print in three sequences to reach all possible dot positions because of the three phases.

The firing frequency and the tilt angle determine the horizontal and vertical resolution of the system, as well as the velocity of the printhead. Or, the other way round, if the firing frequency of the head and the target for the resolution is given, the tilt angle and the printhead velocity are determined. Figure 5 describes the relationship between horizontal resolution and printhead speed for different firing frequencies.

The possible resolutions obtained by changing the tilt angle at a given nozzle pitch are shown in Figure 6. The different curves represent the different tilt ratios. Only the resolutions described by the lines are possible. Not all the resolution combinations make sense. Particularly preferred are the angles with the same horizontal and vertical resolutions. These combinations are defined by the crosspoints of the hyperbolical curves with the straight line vres = hres. vres stands for vertical resolution and hres is the abbreviation of horizontal resolution. In some cases also the other straight lines vres = 1/2 hres or vres = 2 hres might be of interest. Figure 7 shows the dependence of resolution on tilt angle. The specific cases of our printhead resolutions are marked.

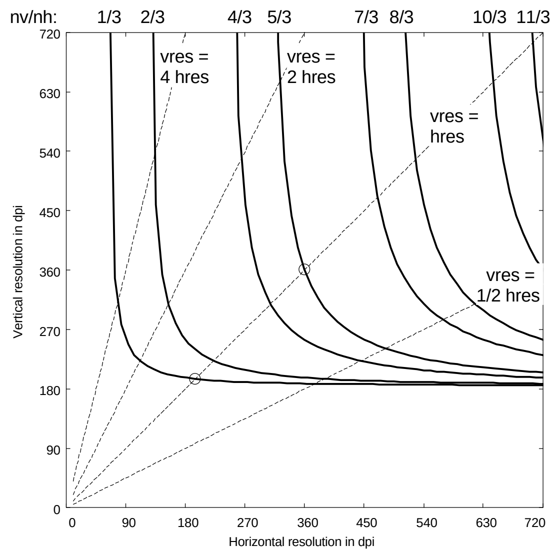

Figure 6. Possible combinations of horizontal and vertical resolution for a given nozzle pitch

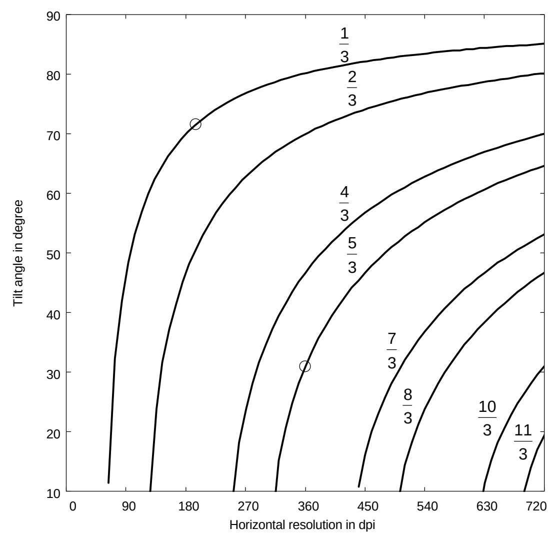

Figure 7. Possible tilt angles for a given nozzle pitch

In order to obtain a high print quality it is of interest to change the horizontal resolution and to print in more than one sequence. Sometimes it is also necessary to increase the print resolution to obtain sharp letter edges, or the opposite, to increase the carriage speed in order to design a draft mode with 180 dpi horizontal resolution.

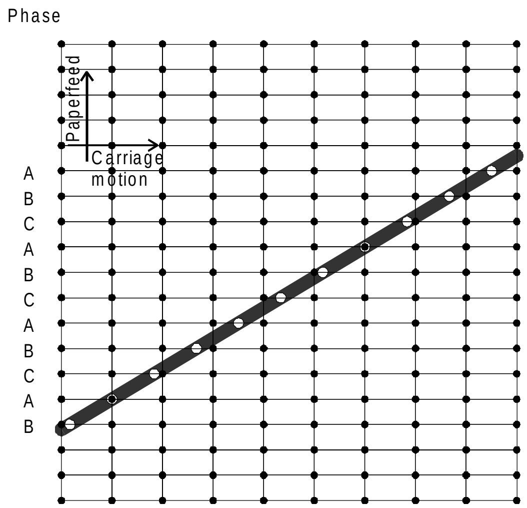

Figure 8. Tilt ratio nh/nv = 2.5/3. Not all nozzles of phase A are in printing position.

The question might arise, whether it is possible to obtain such print modi with the tilted PiezoJet™ head without changing the required maximum firing frequency. As shown in Figure 6 it is possible to change the horizontal resolution without changing the vertical resolution by jumping from ratio to ratio, i.e. from curve to curve. If the carriage speed is increased with the same firing frequency, the result is a smaller resolution. Especially for a 4/3 printhead it is possible to go on a constant vertical resolution to twice the horizontal resolution. Also in the other direction there are possibilities on the 2/3 and 1/3 hyperbole.

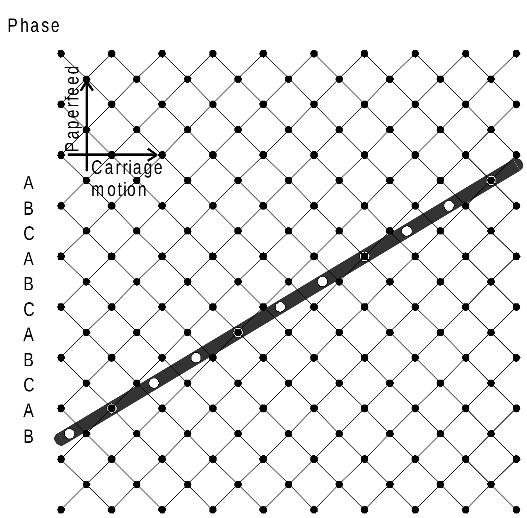

Figure 9. Staggered grid for 2.5/3 ratio. All nozzles of phase A are in printing position.

720 dpi printing on the 10/3 hyperbole is also obtained if one starts with 360 dpi, i.e. with a 5/3 printhead. The multiplex compensation is still working. However, for a 5/3 printhead a 180 dpi resolution is not available because the 2.5/3 curve does not exist.

This becomes more obvious in Figure 8. All phase A nozzles should be fired at the given time, but only half of the nozzles are in printing position. So, this 180 dpi resolution cannot be obtained. As a solution the thinning out algorithm can be changed using a staggered 180 dpi grid (Figure 9).

Design Parameters

A good print quality can only be obtained with the adjustment of the drop volume. For a printhead based on the Xaar principle there are several parameters to adjust the drop volume. Examples are the nozzle diameter, the channel length, the channel width, the channel depth, the electrode depth, the driving voltage and more. All these parameters are interdependent. If one parameter is changed the whole behaviour of the printhead is affected. If e.g. the nozzle diameter is changed, this has an impact on the drop volume and the drop velocity. At the same time also the acoustic length of the channel changes because of a different reflection factor of the nozzle. However, the acoustic length is the basic time for the driving pulse shape. Therefore it is very important to know the relationship between all the variables.

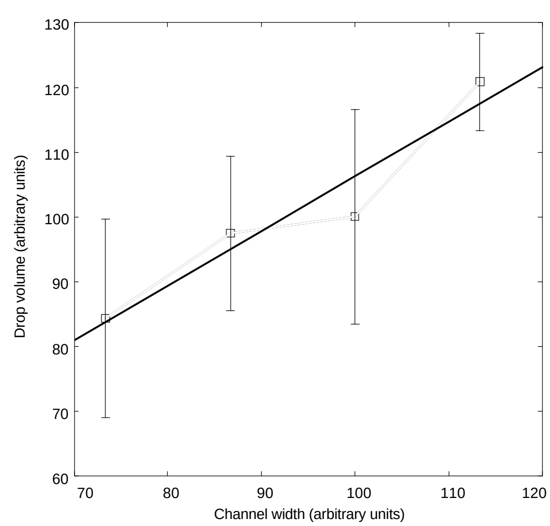

Figure 10. Drop volume versus channel width

In many experiments the dependence of the printhead performance on design parameters has been studied. As an example, the results for various channel widths and nozzle diameters are discussed.

Figure 10 shows the drop volume depending on the channel width. With increasing channel width the wall thickness decreases and the drop volume increases simultaneously. The channel wall has different attributes. The active piezo material of the wall produces the deflection and therefore the volume change of the channel. With a thinner wall and the same driving voltage, the electrical field over the active material is higher. The result is a higher deflection proportional to the channel width. In addition, the stiffness of the wall decreases which facilitates the mechanical deflection. However, at the same time the driving force of the wall decreases. If these effects compensate each other, the deflection should be proportional to the channel width.

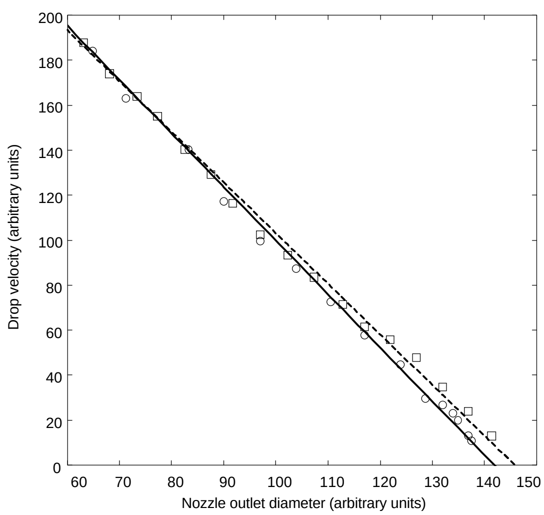

Figure 11. Drop velocity versus nozzle outlet diameter

Another important parameter is the nozzle geometry. Therefore, experiments on the ejection behaviour dependent on this parameter were carried out. Special printheads with different nozzle diameters were produced. The outlet diameter of the nozzle was varied in a wide range within one head. The performance of such heads was studied. Especially the drop volume and the drop velocity were measured. Figure 11 and 12 show the diagrams for these parameters. The drop velocity increases with a smaller outlet nozzle diameter. More interesting is the drop volume. Obviously a maximum exists. It is understandable that the drop volume decreases with decreasing nozzle diameter, but the smaller drop volume for an increasing nozzle diameter is surprising. The change of the nozzle outlet diameter changes the reflection factor of this channel end. This results in a different acoustic length of the channel. The printhead was driven with a constant pulse shape. Consequently there is a mismatch between real acoustic length and the pulseshape, which causes a reduced efficiency of the driving pulse.

Interaction Ink/Substrate

If the task is to design a printhead for a special resolution one of the first questions is about the size of the required drop volume. The answer depends on the ink/substrate interaction. If the spread of the ink droplet on the paper is bigger, then the drop volume can be smaller and vice versa. Many publications are dealing with this problem[6 7 8 9 10].

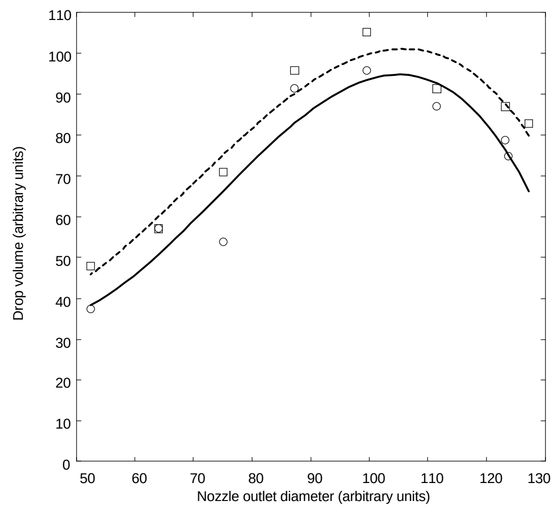

Figure 12. Drop volume versus nozzle outlet diameter

The knowledge of the ink/substrate interaction is necessary to design a printhead for a special resolution and to define the target volume. In the next step the knowledge of the design parameters mentioned above can be used to obtain this volume.

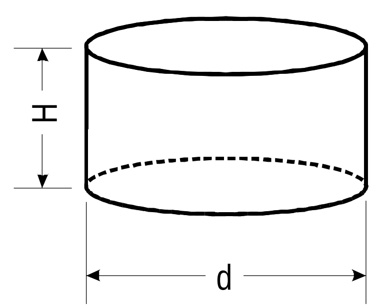

Figure 13. Cylindrical model for the penetration of the drop into the substrate

The dot diameter depending on the ink drop volume was measured on different substrates. Since this measurement is very time consuming, a simple model for the interpolation between the measured points is desirable. This also opens the possibility to extrapolate.

A simple model to describe the ink/paper interaction was developed. Under the assumption that a coated paper absorbs the ink directly without spreading, the coating thickness H determines the height of a wetted cylinder (Figure 13) with the dot diameter d. The correlation of this model is

$$M = \frac{d^2\pi}{4} \cdot \rho \cdot H$$

where M is the drop mass, ρ the specific weight of the ink, d the dot diameter and H the cylinder height. This is a simple assumption, but it describes the recent measurements with the coated paper very well, as can be seen in Figure 14. For the measurements on plain paper this model does not fit as well.

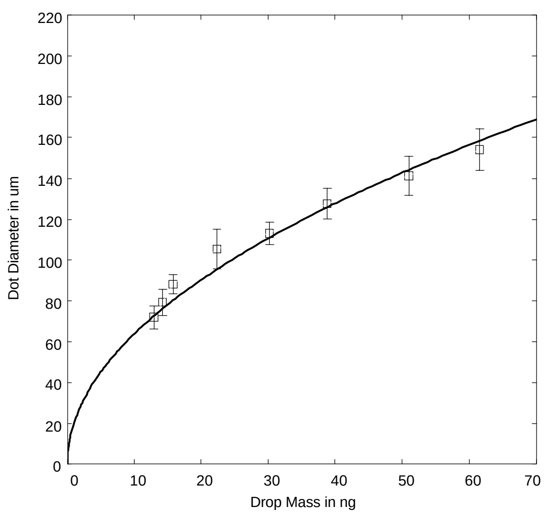

Figure 14. Dot diameter as a function of the drop mass with coated paper as substrate. Curve fit based on a cylindrical model.

Therefore another model was used. Figure 15 shows a sketch.

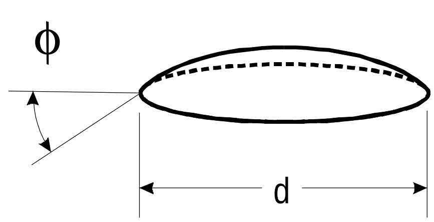

Figure 15. Spherical model

Under the assumption that the ink drop on paper behaves like a sphere with an ink/paper wetting angle ϕ, the correlation is

$$M = \frac{\pi}{48} \cdot \frac{1-\cos(\phi)}{\sin(\phi)} \cdot \left[3 + \left(\frac{1-\cos(\phi)}{\sin(\phi)}\right)^2\right] \cdot d^3 .$$

As can be seen in Figure 16 this model fits well for plain paper.

An uniform description consists of a linear combination of the parameters of both mechanisms. Using this model a good approximation to the measured dot diameters is obtained. This opens the possibility to determine the necessary drop volume for a specified resolution.

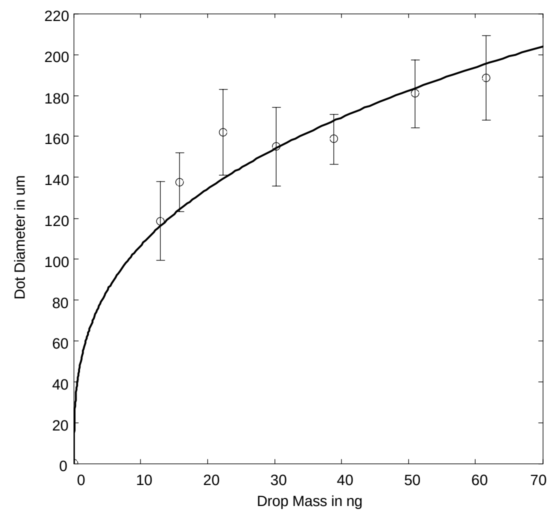

Figure 16. Dot diameter versus drop mass for uncoated paper. Curve fit based on a spherical model.

Conclusion

The knowledge of the ink/paper interaction is the basis of each printhead development. Simple models are helpful for the interpretation of the measured data. Only if this information is available, the necessary drop volume for a special resolution can be determined. For the drop volume adjustment the "shear mode / shared wall" printhead offers a lot of parameters. Moreover, special modi for high print quality or draft printing are available with the PiezoJet™ printhead.

References

1. G. Beurer and J. Kretschmer, "Function and performance of a shear mode piezo head", *IS&T`s NIP13: International Conference on Digital Printing Technologies*, November 2-7, 1997, Seattle.
2. J. P. Harmon and J. A. Widder, "Integrating the Printhead into the HP DeskJet Printer", *Hewlett-Packard Journal*, **39**, October 1988, pp 62,

3. D. J. May, M. D. Lund, T. B. Pritchard, and C. W. Nichols, "Data To Dots in the HP DeskJet Printer", *Hewlett-Packard Journal*, **39**, October 1988, pp 76,
4. J. Shimoda, "New Bubble Jet Head Technologies Used in Canon Color Bubble Jet Printer BJC-70", *Proc. IS&T`s Eleventh International Congress on Advances in Non-Impact Printing Technologies*, 1995, pp.353
5. S. Temple, "Droplet Deposition Apparatus", *WO Patent no. 95/07185*, 1995
6. A. Asai, M. Shioya, S. Hirasawa and T. Okazaki, "Impact of an Ink Drop on Paper", *IS&T`s Seventh International Congress on Advances in Non-Impact Printing Technologies*, October 6-11, 1991, Portland
7. L. Carreira, A. Gooray and L. Agbezuge, "The Effect of Drying Rate on Inter-Color Bleed", *IS&T`s Eleventh International Congress on Advances in Non-Impact Printing Technologies*, October 29- November 3, 1995, Hilton Head
8. J. Borch, "The Effect of Paper Sizing Treatments on DOD Ink Jet Printing at Medium to High Resolution", *IS&T`s 47th Annual Conference: The Physics and Chemistry of Imaging Systems*, May 15-20, 1994, Rochester
9. D. L. Lee, W. H. Fass and A. T. Winslow, "Engineering an Ink Jet Paper. What`s Involved?", *IS&T`s 47th Annual Conference: The Physics and Chemistry of Imaging Systems*, May 15-20, 1994, Rochester
10. J. Borch, "Plain Paper Choices for Ink Jet Printing", *IS&T`s Tenth International Congress on Advances in Non-Impact Printing Technologies*, October 30-November 4, 1994, New Orleans