Technical considerations when designing and building an Industrial ink jet printer

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Abstract

The Task: You have been chosen to design your company's newest inkjet printer.

The Challenge: The printer must have increased productivity with high image quality. How do you calculate the best approach and quantifying your design choices?

This paper will discuss the important inputs required for the design process and steps systems designers should consider when undertaking such an initiative. Including:

- *Printer resolution defined in dots per inch (dpi)*
- *Ink type, solvent, UV, Aqueous or oil based for example*
- *Number of colors required*
- *Productivity measured in m^2/hr*

From these considerations, calculations to predict the drop mass output per jet and the jetting frequency and carriage speed required to build up an image will be introduced.

The goal by the end of the paper will be to identify:

- *The most suitable Dimatix printhead for the intended printer/ application*
- *The speed of the printhead carriage assembly or the media transport under the printheads*
- *The jetting frequency of the printheads*
- *The number of heads required per color*

Addressability Vs Resolution:

It is important to understand the difference between addressability and resolution. Addressability is what the print platform has been designed to achieve with regard to the placement of each individual drop while resolution is what can actually be achieved. In some circumstances, these values can be different. The differences can be a result of the following issues:

- Drop placement errors (head related and from system errors)
- Ink spread variations within a substrate and between different substrates

For example, suppose that a printer platform's addressability has been set to 600 X 600 dpi. This translates to a drop-to- drop spacing of 42 microns.

600 dpi = 1/600" between drops = 1/ (600) X 25.4mm
= 0.042mm

If all of the printer's errors exceed 1/2 of this ideal drop spacing, then the specified resolution of 600 dpi is degraded. Errors can originate from some or all of the following items:

- Drop straightness or trajectory errors from a printhead (figure 1). These types of errors are angular and the associated positional errors increase as the distance between the printhead and substrate increase. Single isolated jet straightness issues in a scanning system architecture are not considered problematic when interlacing and screening methods are used. However, repeating drop placement errors between heads can be difficult to overcome. These errors can lead to streaks in an image and can be one of the contributing factors behind common banding problems found in scanning UV systems.

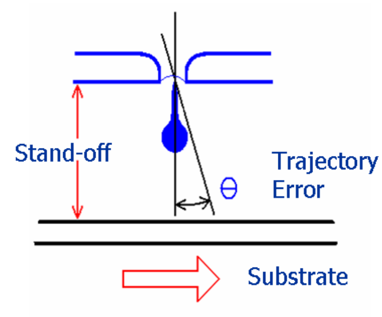


***Figure 1**: Jet trajectory errors*

- Printhead alignment errors (figure 2). These errors originate from problems with aligning multiple heads within a color and alignment between the colors. Printheads have their own specifications and tolerances and any alignment procedure should be based upon a best fit approach. Once aligned, the mechanical mounting should be stable over the complete operating temperature range and the maximum acceleration specified within the scanning architecture design.

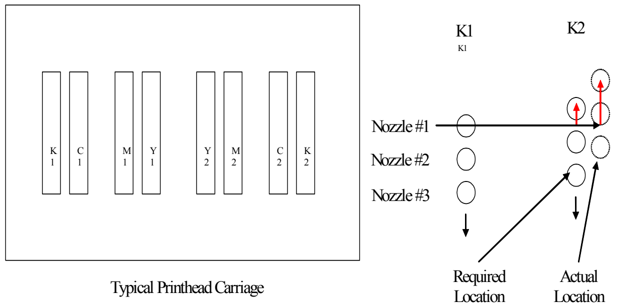


Figure 2: Head alignment errors

- Carriage alignment errors,(figure 3) These can be produced by incorrectly aligning the carriage to the carriage motion.

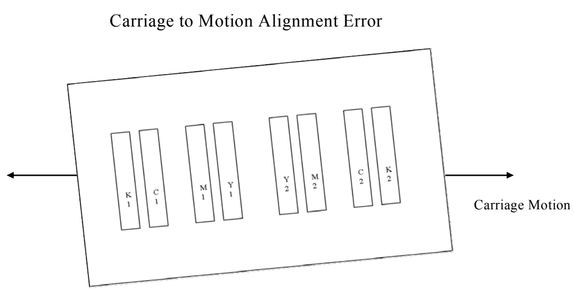


Figure 3: Carriage to motion alignment error

- Carriage weave issues,(figure 4). This is perhaps a less common problem, but one that can result from using a low grade motion system. As the carriage crosses the scan path, it may oscillate in the cross process direction producing drop-on-drop placement errors.

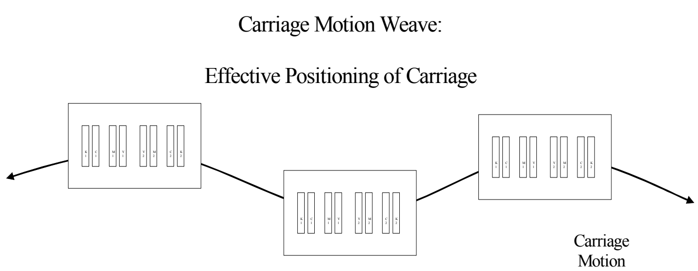


Figure 4: Carriage motion weave

- Electronic issues including encoder and fire pulse can also contribute to increased errors. Encoder jitter can result in printhead performance issues. An encoder set with the wrong resolution can also result in drop placement errors in the scan direction.

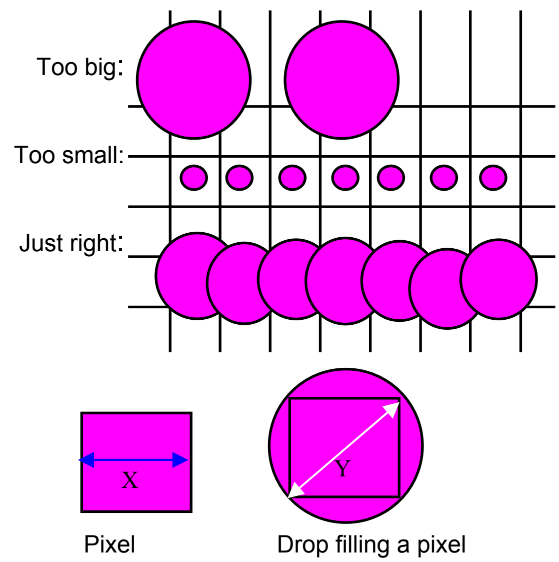
Drop spread estimate:

When the desired addressability and a reasonable system error budget allocation have been established, the next step is to determine the drop spread of the ink on the intended range of substrates. Specifically, to determine the drop size output from the printhead in order to achieve a solid area fill at the defined dpi, while at the same time meeting the resolution is required. Information required for this is:

- Drop spread measurements made with the ink jetted with various drop sizes on target substrates
- Charting of this data so that some extrapolation can be made for drop sizes with no data.

In general, this data is usually provided by the ink partner or ink supplier. [1]

Once the drop spread data is complete, construct a simple calculator that allows you to vary the process and cross process addressability (in dpi) and error estimates while looking at the rate of under or over fill. The program should also incorporate the printer errors discussed above. For simplicity, assume that drops are round when they land on the substrate and require about a 41% overlap to achieve solid area fill. Figure 3 shows how this is done.



Pixel size = X
Drop size = Z
Z = S2X or 1.41X

Figure 5: Filling pixels with round drops

Example calculation:

1. What is the addressability?
   600 X 600 dpi
2. Printer error budget:

Jet straightness

Use 3X typical value	3 X 4 mRad or 12 microns at 1mm standoff
Scanning carriage accuracy	12 microns maximum
Media advance accuracy	12 microns maximum
RMS estimate for all errors at 1mm standoff	21 microns

3. Solid area fill will therefore require an ideal round spot size of:
   Pixel size for (600 X 600 dpi) or X = 42 microns
   An extra 40% to fill the pixel with a round drop
   Plus the 21 microns RMS systems error value
   For a total drop spread size of 81 microns.

Drop volume estimate:

The next step is to determine what drop volume from the jets is required to meet this 81 micron minimum value on the range of substrates you intend to print.

Table 1 provides typical data for ink spread on a standard set of substrates. This type of data is typically supplied by the ink supplier or collected during the evaluation phase of the project.

Table 1

Ink type	Drop mass / ng	Typical drop spread range / microns
Solvent	30	80 – 150
	50	100 – 180
	80	120 – 220
UV	30	70 – 130
	50	100 – 160
	80	130 – 220
Aqueous	30	70 - 170
	50	110 - 200
	80	160-260

This table also shows the type of variation in drop spread typical from different substrates. For the example described above while jetting UV ink, an 81 micron spot size can be achieved with a 30ng drop.

Printhead choice:

Table 2 describes the printheads available from Dimatix, with their optimum drop volume and compatible inks. The column matching printheads with recommended addressability has been derived using the information provided in Table 1.

Table 2 [2]

Head type	Number of Jets	Ink Compatibility	Drop vol/pl	Addressability range / dpi
Nova	256	UV, Solvent, Water	80	200 – 450
Galaxy	256	UV, Solvent, Water	80	200 – 450
		UV, Solvent, Water	50	300 – 500
		UV, Solvent, Water	30	450 – 700
SL	128	UV, Solvent	80	200 – 450
SM	128	UV, Solvent	50	300 – 500
SE	128	UV, Solvent	30	400 – 700
Skywalker	128	Solvent	50	300 - 500
Q-30	256	UV, Solvent	30-80	300 – 600
Q-10	256	UV, Solvent	10-30	450 – 800

For the same example above with a desired addressability of 600 X 600 dpi, using UV ink and 30 drop size, the suitable printheads include:

Galaxy 30
SE-128
Q-30

The use of the larger drop volume option of 50pl is also a possibility but will result in a decrease in resolution (due to greater ink spread) as compared to the 30pl drop size, but higher productivity may compensate for the degradation of image quality. For this first calculation, presented below, we chose the Galaxy 30pl.

Interlacing and screening techniques:

Productivity is dependant on the level of image quality that is required. Below is a brief description of some of the common techniques used:

1. Interlacing
   Instead of printing a line of pixels with the same jet from a single printhead, the following can be used:

- Inter head interlacing is when different jets from the same head are used to print the line of pixels. This is done by multiple passes with each pass only partially filling in the line. This is a useful technique when there is only one head per color in the printer.

- Head-to-head interlacing is when different jets from two or more different heads of the same color are used to print the line of pixels. Again, multiple passes are required.

The end result is that each level of interlacing requires more passes which in turn, reduces the printer productivity. Adding more heads per color or running the heads and motion system faster are strategies used to win back some of the lost productivity.

2. Stochastic screening

This is a screening technique where the image is randomly divided into two or more parts with each part printed separately. This screening technique can be done in combination with interlacing and can help reduce structured errors through randomization.

When we describe 1- pass, 2-pass, 4-pass etc, we describe various levels of interlacing and / or screening. For example, 4- pass means the image is divided into 4-scans, each scan basically filling in only ¼ of what it is possible with that printhead. 4-pass will take a little more than 4 times as long to complete compared to one pass but will compensate for missing jets and straightness problems.

Printer profile:

Scanning printer architectures are mostly efficient but they do require ramp times for the beginning and end of each scan. During these times the fire pulse to the printhead is generated by a position encoder attached to the moving carriage or moving substrate. During the acceleration and deceleration phases of the scan, the encoder is sending rapidly increasing and decreasing head fire frequencies. This can cause output variations from the printhead which can in turn lead to jetting issues and is why printing should be avoided during these ramp times.

The longer the print width the better the ratio between printing and non printing ramp times.

In this section we are calculating the total time for each scan. Inputs required include:

Printhead type	Galaxy 30 AAA
Number of jets / head (j)	256
Drop volume (dv)	30pl
Number of colors (CMYK)	4
Maximum print frequency	20kHz
Horizontal addressability (Y)	600
Vertical addressability (X)	600
Number of print passes	np
Maximum acceleration allowed (a)	[1].5g
Print width (W)	2.5m
Carriage width (w)	[2]0.4m
Settling time at the end of each scan	100ms
Productivity	50m^2/hr
Number of heads / color	nh

1 The value used here is lower than the limit which can cause de-priming in the printhead through rapid movement of the ink column above the printhead. This can depend on the remote reservoir design and location. The lower number is also used to avoid overstressing the mechanical system.

2 The carriage width is necessary in the calculations since the mounting of all of the printheads for all of the colors will take up space which needs to be also covered in each scan.

Motion equations required:

$$v^2 = u^2 + 2*a*s \qquad (1)$$
$$v = u + a*t \quad (2) \qquad t = s/v \quad \text{when } a = 0 \qquad (3)$$

Where s = distance traveled
u = initial velocity
v = final velocity
t = time for travel
a = acceleration
g = acceleration due to gravity = 9.81m/s^2

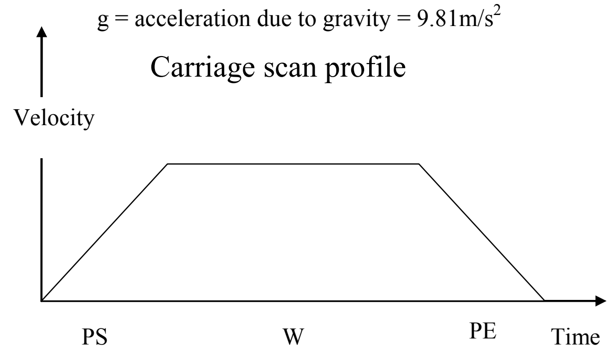


***Figure 4**: Carriage scan profile*

Maximum scan velocity = Maximum print frequency / Process dpi
= 20,000/600
= 0.85m/s

Print start position (PS) = $v^2/(2*a)$ from (1) with u =0
Print end position (PE) = 0.074m

Ramp up time = v / a from (2) with u =0
= 0.17sec

Print time + overshoot = s/v from (3)
= (2.5+0.4)/0.85sec
= 3.4 sec

Ramp down time = 0.17 sec

Total time per scan = 0.17 + 3.4 + 0.17 +0.10
= 3.84sec

Productivity calculation:

With the scan times and printhead type established, the actual printer productivity can be estimated along with some other useful information:

Print efficiency / %
Ink lay-down / ml/m^2

Print efficiency is calculated by determining the ratio of time to print 2.5m (2.5 / scan speed) to the total scan time, including ramp up and down times and settling times.

Ink lay-down is a measure of how much ink column is dispensed per unit area per color.

Productivity calculations required:

Print efficiency (PE) = Printing time of scan / Total scan time
= (2.5/0.85) secs / 3.84secs
= 78%

Productivity (P) = (n*.0254/X dpi)*(v*PE*3600/np) m^2/hr
where n = j*nh

Therefore, nh = (P/j)/ ((.0254/X dpi)*(v*PE*3600/np))
= (50/256) / ((.0254/600)*(.85*.78*3600/1))
= 2 Galaxy 30's

Using only one scan, no interlacing and all jets firing, the productivity of 50m^2/hr can be achieved by using two Galaxy 30pl heads per color for a 600 X 600 dpi, 2.5m print width application.

Ink lay-down = (X dpi* Y dpi/.0254^2)*dv x10^{-9}
= 17ml/m^2

Total number of printheads = 8 per printer

Further productivity calculations:

Another example is used to further explain these calculations:

Productivity	8m^2/hr
Print width	2.5m
Ramp and settling times	Same
Horizontal addressability (Y)	360 dpi
Vertical addressability (X)	300 dpi
Number of passes	[1]4
Ink type	Solvent
Printer error budget (same)	27 microns
Solid fill spot size required	138 microns
Drop volume required	50pl

[1] 4 pass is a more realistic printing situation where typically ¼ of the jets are firing at any one time as the image is scrambled for interlacing and / or screening.

Type of printhead: Galaxy 50 or
SM or
Skywalker

Chosen for this example is a Skywalker printhead with 128 jets

Maximum print frequency 16kHz

Maximum scan velocity = Maximum print frequency / Y
= 16,000/360
= 1.1m/s

Print start position = v^2 / (2*a) m from (1) with u =0
= 1.1^2/ (2*9.81/2)
= 0.12m

Print start time = v / a sec from (2) with u =0
= 1.1 / (9.81/2) sec
= 0.22sec

Print time + overshoot = s/v from (3)
= (2.5+ 0.4)/1.1sec
= 2.64 sec

Print end time = 0.22 sec

Total print time per scan = 0.22 + 2.64 + 0.22 +0.10
= 3.18sec

Print efficiency (PE) for one pass = Printing time of scan / Total scan time
= (2.5/1.1) secs / 2.86secs
= 71.5%
PE for 4 passes = 18%

Number of heads or nh = (P/j)/ ((.0254/X)*(v*PE*3600/np))
= (8/128)/ ((.0254/300)*(1.1*.18*3600/4)

~ 4 Skywalkers per color
~ 16 Skywalkers per printer

Ink lay-down = (X dpi* Y dpi/.0254^2)*dv x10^{-9}
= 8.4ml/m^2

Summary:

Without delving into the extended topic of image quality and the use of interlacing and screening methods, a procedure to estimate the type and number of printheads has been established. The procedure is flexible enough that variations can be made in the application requirements and new results determined quickly.

These calculations are meant to provide a first order estimate of what is ideally possible with various Dimatix printheads when used within a scanning printer. A final mention of issues not discussed in the calculations is important as they will also affect printing efficiency and productivity.

1. What is the head layout when multiple heads per color are required? Are the heads positioned end jet to end jet for maximum throughput or offset ¼ or 1/3 or ½… head length for head to head interlacing.
2. How fast can the ink be dried or cured. Using many printheads may increase productivity, but if scanning is too quick for the solvent heat dryers or curing lamps to completely 'dry' the ink, then productivity will have to be reduced.

References

[1] We recommend that you refer to Fujifilm Dimatix (FD) document, PDS00020, Ink Reference Chart for a complete listing of our recommended ink vendors.

[2] We recommend that you refer to Fujifilm Dimatix (FD) document, PDS00015, Printhead Reference Chart for a complete listing of our printheads.

Author Biography

Terry O'Keeffe has worked with Dimatix piezo ink jet printheads over 8 years, primarily in applications and service support. He has a diverse background in systems engineering and applications development with over 10 years experience with high powered UV lasers and laser material processing. For the past five years, He has been Technical Support Manager in Europe, assisting OEM integrators with many different digital-dispensing applications.