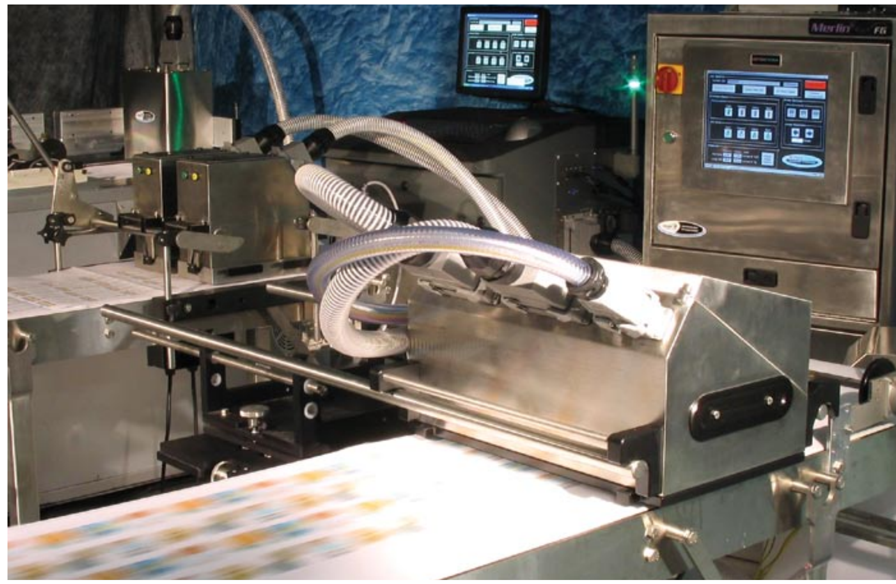
Single-Pass Digital Production Printing and Deposition

Inkjet's Applications, Advances and Advantages as an Industrial Manufacturing Method



Digital inkjet technologies are increasingly being adopted as an industrial fabrication method for depositing new exotic materials. However, inkjet has found success over the years in numerous commodity product-fabrication applications as well.

This article reviews the various inkjet technology types and provides pros and cons of thermal, piezo and continuous inkjet in industrial-use applications. We'll look at the various criteria, from economic considerations to process practicality, to consider when assessing if digital fabrication techniques are appropriate. Finally, the article offers several commercial examples, ranging from high-end electronic device fabrication to digital coatings and commercial food decoration.

The use of inkjet as a commercially viable method for applying text and graphics onto a variety of print media is well established. There are numerous examples of inkjet printing machines, ranging from small office/home office (SOHO) applications (typically thermal inkjet) to mid- and high-end commercial printing systems (predominately using piezo technology).

To date, there has been much discussion but little disclosure relative to using inkjet in true industrial operations. Much of what has been disclosed has focused on device fabrication for electronic materials; conducting traces, logic devices, RFID, all kinds of displays and solar panels.

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Inkjet has received little attention in several important, but less prominent, applications. This may be a result of inkjet use in industrial applications, which often requires custom or unique system design. Furthermore, companies often view these pioneering efforts as a competitive advantage and aren't willing to publicize their use.

Industrial Environments

Before discussing inkjet's attributes, it's useful to consider the term "industrial inkjet." There are many examples of commercial inkjet printing systems. These systems are generally available, and used for print-for-pay applications. These printers jet onto known traditional media, and are often stand-alone devices.

Commercial inkjet printing systems include the SOHO, direct-mail and super-wide graphic printing systems. Industrial applications generally:

- Do not use standard media
- Are part of a process to fabricate or manufacture a product
- Are an inline process
- Have high volume
- Aren't usually print-for-pay
- Are custom-configured or purpose-built
- Are manned by lower-skilled operators
- Operate in dirty environments
- Are used in 24/7 operation with little operator intervention

There are numerous examples of inkjet systems used for coding and marking.

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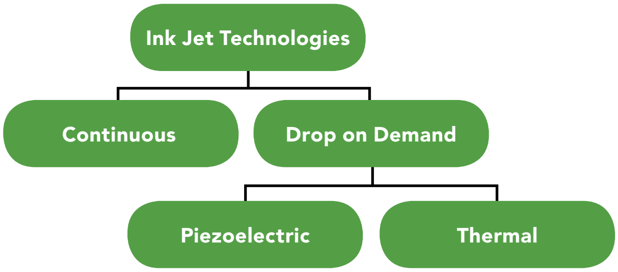

Figure 1: Inkjet Technologies

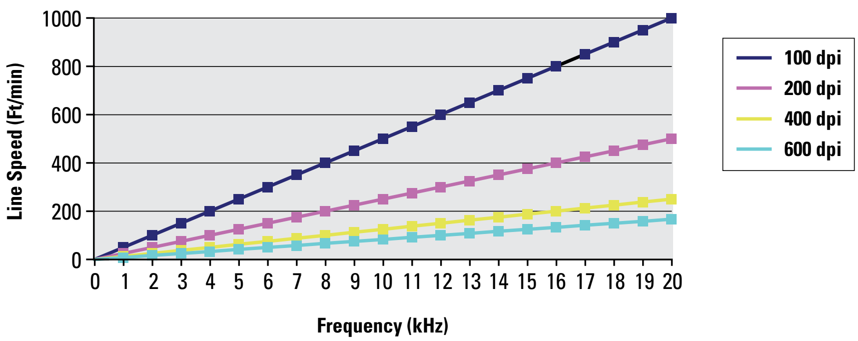

Figure 2: Line speed vs. jetting frequency for various in-process addressability

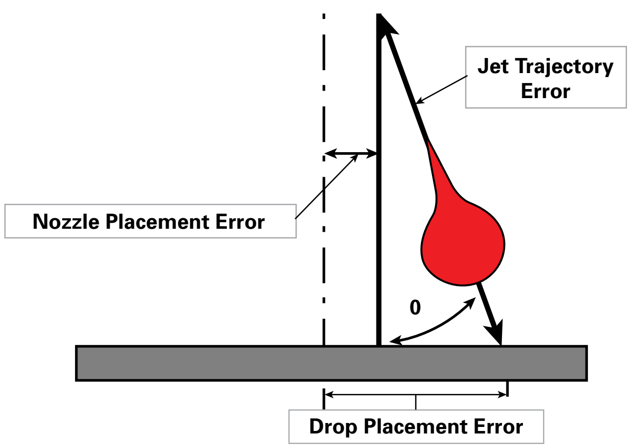

Figure 3: Effect of nozzle placement and Jet trajectory on drop placement

Figure 4: Single jet firing vs. all jets firing — showing minimal cross-talk

These arguably fall into the realm of "industrial inkjet," but are secondary to the actual production or product fabrication. "Industrial inkjet" is a term used to define inkjet technologies that are an integral part of the product manufacturing process.

Inkjet Printing Technology

Inkjet is broadly divided into two major technologies: Continuous Inkjet (CIJ) and Drop-on-Demand Inkjet (DOD). DOD is further divided into Thermal and Piezo. (See Figure 1)

CIJ Attributes

Continuous inkjet employs a stream of fluid that passes over two charge plates: The first charges the droplets and the second defects them into a gutter or onto the substrate.

The ink types used in this technology are typically dye-based, solvent-based inks for multi-defection, single-stream versions (typically used in small character date coding), and dye-based, water-based ink for binary-deflection, multi-nozzle arrays (typically used for document printing).

The print speed, and subsequently the line speed, for these system types are high, but there are challenges in developing inks, especially with the pigments.

Attributes of DOD Thermal

DOD Thermal Inkjet (sometimes referred as "Bubble-Jet") uses heating elements situated close to an array of nozzles. To actuate the nozzle, the associated heating element rapidly heats. This vaporizes components in the ink (typically water) in proximity to the heating element, producing a bubble that forces ink out of the nozzle. Upon cooling, the bubble collapses and ink is drawn into the channel by capillary action ready for the next actuation.

This technology is predominant in home-office printers. The inks are limited to fluids that have an evaporable content (typically water). The jetting frequency and device lifetime also are limited. The major benefit is the unit cost, although this may not be economical when considering the number of head replacements needed over the system's lifetime.

Attributes of DOD Piezo

Piezo inkjet (sometimes referred as "Impulse Jet") is a technology that uses the deforming nature of piezo-electric ceramics to impart pressure pulses to defined-ink chambers. These pressure pulses cause droplets to be ejected when they encounter the nozzle's small aperture.

There are several internal architectures employed by various vendors (shared wall and individual channels) and several methods of exciting the piezo materials (extension mode, shear mode and bend mode). Some head configurations, owing to the internal architecture, allow all jets to be fired simultaneously, while others must use a series of alternating nozzles. Some have benign ink-fluid paths, while others have electrical contacts in the fluid paths.

However, in general, Piezo inkjet printhead technologies can fire at medium jetting frequencies (10-30 kHz), and tolerate a wide range of ink chemistries. One of the shortfalls for some ink chemistries is nozzle open time. Since these devices do not eject drops unless actuated, fast-drying inks will quickly dry in the nozzles and occlude the jets. For reliable operation, care must be taken to design appropriate capping and maintenance stations.

Inkjet Technology and Application Criteria

For an industrial application to be successful, the user needs to review many interdependent, physical, technical, operational and economic criteria to assess suitability. Successful implementation of industrial inkjet technology in a manufacturing process is determined by the type of inkjet technology used and the resulting system architecture.

Other important considerations include:

- Application suitability
- Print-head technology suitability
- Systems integration

Application Suitability

Choosing inkjet as an industrial process should be thoughtfully considered. Major factors that determine if the application is a fit with inkjet are application requirements for data variability and product run-length.

The economic factors of applications that fall into these criteria are often difficult to determine, as the costs savings aren't in direct cost-per-piece comparisons, but in savings from labor, secondary processes, inventory, scrap and turnaround times.

In general, if there is a suitable alternate method of imaging, inkjet may be lower quality, technically more challenging and more expensive (both in capital and ongoing run costs).

Applications in which inkjet enables a new process methodology or (ideally) is the only viable production method are much more compelling (i.e., inkjet adds value versus decreasing cost).

Questions to address when considering inkjet:

- Is the use of inkjet a new process step or is inkjet going to replace a current method of production?
- Why is inkjet being considered?
- What are the technical and economic benefits?
- Is there an inkjet ink or fluid available?
- Is the inkjet quality acceptable?
- Does this process add value, reduce cost or reduce time?
- Is there a place in the process where inkjet is essential?

If any of these questions result in reservations or doubt, carefully review your plans to use inkjet.

Print-Head Technology Suitability

In determining if inkjet is suitable for a specific industrial application, print head technologies and options need to be reviewed. The following criteria is a guide of the various inkjet parameters that should be considered and compared:

- **Ink options** - How robust is the jetting component with the target chemistry? Will the head jet the fluid that your process requires?
- **Print head robustness** - How resistant is the physical construction of the print head to the operating environment in which you expect to be jetting?
- **Number of nozzles and packing density** – Based on your required image quality and the jet density of the base print head module, how large is the required head cluster going to be? This affects the precision requirements of your substrate motion and the jet quality of the inkjet device.
- **Jetting frequency** – At the desired line speed and required print addressability, does the proposed jetting technology meet your requirements? (See Figure 2)
- **Straightness** – Since most industrial applications are trending toward single pass, high-jet straightness is essential for good quality imaging and high resolution printing. Simple calculations of jet straightness, drop mass, product standoff and product velocity will determine if the print head can image the required resolution for high-quality imaging. (See Figure 3)
- **Drop mass and variations** – It's essential to understand the acoustic properties of the jetting process and the frequency effect on drop mass. Inkjet structures typically have variable-mass outputs as they progress through the frequency range. In some cases, increasing the line speed results in improved jetting performance.
- **Drop velocity and uniformity** – Like drop mass, drop velocity also varies with jetting frequency. Mass and velocity can be affected by a phenomenon known as "cross-talk." Cross-talk is the measured effect on mass and velocity when a jet's performance varies, depending upon if it is fired alone or simultaneously with other jets (typically adjacent). (See Figure 4)
- **Drop-mass modulation** – Inkjet heads are predominantly binary. That is to say, you either produce a drop or not. It is not easy to create grey levels. When evaluating print heads with the ability to produce variable drop masses, drop-velocity control is also essential. The smaller drop and the larger drop must land on the substrate in the appropriate location. To do this, their drop velocities need to be matched. (See Figure 5, page 34)
- **Head life** – Head life is a function of the print head's ruggedness, fluid jetted, environment and maintenance procedure. If a print head requires frequent wiping, care must be taken to design the maintenance protocol or choose a print head with a robust nozzle plate.
- **Throughput and output** – Published performance specifications of inkjet technologies tend to vary from vendor to vendor. A commonly adopted evaluation metric is "nanogram kilohertz." To calculate this, multiply the nominal drop-mass by the jetting frequency and then de-rate that by any limitations in the duty cycle. If all jets cannot fire simultaneously, de-rate by the alternating sequence (e.g., divide by 3). If the head self-heats, de-rate by the recommended duty cycle (e.g., 30 percent). This will show the raw throwing power of the device and provide a good metric for comparing technologies.
- **Price and economics** – A system's economics reach far beyond the simple print head technology cost. Downtime, operator intervention, scrap, run costs, maintenance costs, product quality and marketability are all factors, and should be considered holistically.

Systems Integration

The decision to either act as your own system's integrator or use the services of an inkjet integration specialist will come down to economics, abilities and interest. If you expect to integrate inline equipment, it is generally better to have the system

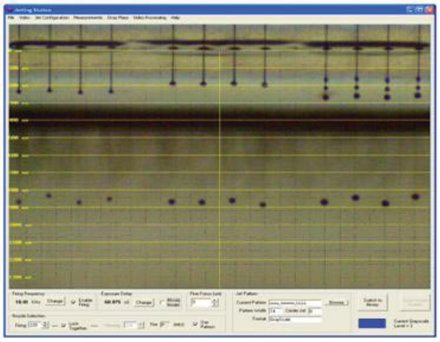

Figure 5: Three drop masses from a common nozzle plate showing uniform velocity and drop placement Dimatix VersaDrop ™

designed, fabricated and supported by an external group. Additional considerations include:

- **Substrate motion** – How accurate is the current substrate motion? Does the current process require additional engineering efforts to control the substrate motion for the intended application? Whose responsibility is it?
- **Print head cluster mechanical tolerances** – Do these fall within the acceptable system error allocations? What is the field repair or replacement strategy? Is it a drop in replaceable unit or will it require adjustment?
- **Print head cluster mounting** – Whose responsibility is it? Can it be done with appropriate precision? What about product avoidance features and park-and-tend stations?
- **Ink properties** – What are the nozzle open time and maintenance requirements? Will the substrate need pre- or post-treatment? Will the ink cure or dry in the current process? If the system and ink are not supplied by the same supplier, who is responsible for the systems operation, support and warranty?
- **Ink lay-down protocol** – Do the ink properties vary with lay-down order, cure protocol and substrate variations?
- **Data path** – What are the data path's needs: Fixed imaged, repeated-fixed image sets, variable images, contiguous images or multi-laned product images? The considerations continue, but it's appropriate that these questions be addressed by the end–use customer and integrator. The relationship between an industrial user and its systems supplier is much more of a long-term partnership than an initial sale. The end user is going to rely on the integrator to ensure the production line is running on a high availability. High-quality engineering, technical competence in all the disciplines and operational support is mandatory.
- External I/O – Typically in industrial environments, the inkjet process is part of a production process. At a minimum, the inkjet controller will need to have the capability of communicating its status (such as printing, not printing and alarm) to the line PLC. In some cases, the inkjet controller may be required to provide line control, such as scrap gate actuation, UV lamp shutter actuation or line stop.

Industrial Application Examples

Successful applications are those in which all of the technical criteria are met and the economics make sense. The following are examples of successful industrial inkjet:

Applications	Key Attributes
Food Decoration	Non-contact, variable data
Liquid Crystal Displays	Replaces spin coating for large displays, non-contact
LEP Displays	Precision deposition
Flooring ceramics and laminates	Variable imaging
Wood graining	Variable imaging
Scratch-resistant coatings	Fast setup, non-contact
Electronics deposition	Replaces costly multi-step process
Specialty Textiles	Variable imaging, embed-ded information
Photovoltaics	Finer features than current method, non-contact
PSAs and Glues	Variable imaging, precision deposition

The use of inkjet as a mainstream, single-pass production process is emerging as a viable alternative to other process methods. Its selected use in appropriate applications has resulted in significant technical and commercial successes.

With continued adoption and further system progress, it is expected inkjet will be a dominant manufacturing process that plant engineers will consider for a host of production applications.

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