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Printed electronics –
Part 302-1: Equipment – Inkjet – Imaging based measurement of jetting speed

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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The text of this standard is based on the following documents:

FDIS	Report on voting
119/168/FDIS	119/183/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

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INTRODUCTION

Inkjet technology uses micro nozzles to precisely eject droplets. For printing, these droplets are patterned on a substrate. Inkjet is a mature technology that has been used widely in home, commercial, and industrial applications. When using inkjet technology, the volume of a droplet can be controlled down to the tenth of a picoliter (pl). Furthermore, the droplet can be placed onto the substrate with an accuracy of micrometers (µm). Because of these features and others, inkjet technology has emerged as one of the most powerful tools for patterning electronic devices, medical dispensing, high precision industrial applications, and more. Inkjet patterning for electronics is an additive process wherein the addition of multiple layers of the pattern does not require the removal of any previously deposited material, unlike the conventional photolithography process. Inkjet also reduces waste when used in more traditional printing applications and when it is used for dispensing. As a result, inkjet technology significantly reduces waste of what are often very expensive materials and is also more environmentally friendly.

As applications for inkjet broaden, a wider variety of jetting materials should be dispensed precisely from inkjet heads. For both new and traditional applications, droplet behaviour from the inkjet head should be measured properly to evaluate and control jetting behaviour. Vision-based measurement techniques are widely used in inkjet-based manufacturing systems, since physical insight into jetting behaviour can be obtained from visual images. The droplet jetting speed and droplet volume are the most frequently measured jetting performance parameters obtained from droplet images.

Using information obtained from vision-based measurement systems about inkjet droplet formation and characteristics, developers can adjust ink formulations and jetting parameters, in order to improve performance.

Note, however, that the measured jet performance and evaluation may vary considerably according to the measurement method since there is no standard measurement procedure available. It may be difficult for process engineers to judge the data sheets of jet performance provided by ink and inkjet head manufacturers since there are no fair test methods, thus causing potentially untrustworthy results. Therefore, the purpose of this document is to provide a standard inkjet measurement method.

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1 Scope

This part of IEC 62899 specifies the method for determining inkjet drop speed based on visualized droplet images obtained by a drop analysis system. This measurement standardization is limited to drop-on-demand-type of inkjet and is not applicable to continuous inkjet. This document includes the test process, image processing software algorithm, and analysis of jetting behavior.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
inkjet printing
type of printing in which a digital image is created by propelling droplets of ink onto a substrate

3.2
drop analysis system
vision-based equipment that can both image and measure inkjet droplets

3.3
drop speed
distance divided by the time it takes the drop to traverse the distance

3.4
drop delivery speed
total distance between the inkjet print-head nozzle plate and the substrate, divided by the time interval between jet triggering and drop arrival

3.5
drop trajectory
drop's direction of travel, often characterised as an angle relative to the nozzle plate

3.6
drop repeatability
droplet jetting behaviour whereby each drop ejected from the nozzle is the same as every other

Note 1 to entry: Drop repeatability is often visualized by displaying individual drops, one per frame, so the characteristics of each can be compared and contrasted. It is quantified by measuring the standard deviation of the drops.

3.7
drop trace
plot of droplet locations from sequential images to understand jetting behaviour including ligament and satellites

3.8
single event imaging
method of capturing each drop image that represents a single jetting event

Note 1 to entry: Raw images of individual drops are in no way added or averaged to produce the final image.

3.9
multiple event imaging
method of capturing each drop image that represents an average or sum of multiple jetting events

Note 1 to entry: Raw images of individual drops are added or averaged to produce the final image.

3.10
single flash mode
LED or high power light that is flashed once per jetting event

Note 1 to entry: Single flash mode may be used with single- or multiple-event imaging.

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3.11
double flash mode
LED or high power light that is quickly flashed twice per jetting event, thereby capturing the same individual drop in two different locations within the camera field of view

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Note 1 to entry: Double flash mode may be used with single or multiple event imaging.

3.12
sequential image
series of jetting images starting from the jetting trigger signal to the time of interest

Note 1 to entry: Sequential images can be obtained from the drop analysis system by increasing the trigger delay of the flash with respect to jetting signal.

3.13
jetting speed curve
jetting speed plot with respect to time, which is calculated from the drop trace

Note 1 to entry: The information includes the relative jetting speed of the main droplet with respect to satellites.

4 Inkjet jetting speed measurement

4.1 General

Inkjet jetting speed shall be measured by using one of the following methods, unless there is a user and supplier agreement. See Annex A for additional information on inkjet measurement methods.

4.2 Process for measurement of drop delivery speed (method 1)

This process describes the measurement method for drop delivery speed from the time of the jetting trigger to the time the drop reaches the target location.

1) Commence printing with the desired specifications (frequency, ink selection, waveform, etc.). It is recommended to record the jetting conditions, in addition to those described in Clause A.6.
2) Specify the target stand-off distance S from the nozzle surface, which usually corresponds to the distance between the nozzle surface and the substrate.

   NOTE Stand-off distances between 0,3 mm and 2,5 mm are typical.
3) Determine the time (T) for the leading edge of the droplet to reach the target stand-off distance by increasing the delay time of the strobe light flash. This process may be performed automatically, or manually. The duration of the flash should not be greater than a few hundred nanoseconds to avoid image blur of the droplet. The flash intensity should be sufficient to allow discrimination between the drop edge and the background, without saturating the image.
4) The drop delivery speed V can be calculated as:

$$V = \frac{S}{T} \tag{1}$$

5) The calibration factor F (µm/pixel) should be determined at the optical magnification used by the drop analysis system to determine drop delivery speed (m/s) from Formula (1). The bottom locations of the droplet are used for the droplet location if the droplet has a long ligament.

4.3 Process for measuring instantaneous jetting speed using single flash mode (method 2)

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This process describes the measurement method based on a single flash for instantaneous jetting speed when the droplet reaches the target location.

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1) Commence printing with the desired specifications (frequency, ink selection, waveform, etc.). It is recommended to record jetting conditions, as described in Clause A.6.
2) Specify the target location. The target location (stand-off distance) usually corresponds to the location of the substrate media.

   NOTE Stand-off distances between 0,3 mm and 2,5 mm are typical.
3) Determine a starting trigger delay time (t_1) of the strobe light flash, at which the drop is slightly above the target location. The smaller the distance of the drop above the target location, the smaller the distance over which the average drop velocity will be calculated.
4) An image is captured and analysed at trigger delay t_1 to determine P_{x1} and P_{y1}, the position of the droplet (center or leading edge) in the x and y directions, respectively.
5) Determine the ending trigger delay time (t_2) of the strobe light flash, at which the drop is slightly below the target location. The smaller the distance of the drop below the target location, the smaller the distance over which the average drop velocity will be calculated.
6) An image is captured and analysed at trigger delay t_2 to determine P_{x2} and P_{y2}, the position of the droplet (center or leading edge) in the x and y directions, respectively.
7) The drop speed V is calculated as:

$$V = \frac{\sqrt{(P_{y2} - P_{y1})^2 + (P_{x2} - P_{x1})^2}}{t_2 - t_1} \tag{2}$$

8) The calibration factor F (µm/pixel) should be determined at the optical magnification used by the drop analysis system to determine the instantaneous jetting speed (m/s) from Formula (2). The bottom locations of the droplet are used for the droplet location if the droplet has a long ligament. If Δt is too short, the jetting speed error due to image quality will be amplified. If Δt becomes large, a long-term average jetting speed is obtained instead of the instantaneous jetting speed at the target location.

4.4 Process for instantaneous jetting speed curve (method 3)

This process describes the measurement method for jetting speed curve.

1) Commence printing with desired specifications (frequency, ink selection, waveform, etc.). It is recommended to record the jetting conditions, in addition to those described in Clause A.6.
2) Specify the target location. The target location (stand-off distance) usually corresponds to the location of the substrate media.

   NOTE Stand-off distances between 0,3 mm and 2,5 mm are typical.
3) Determine the final trigger delay time (T_f) of the strobe light flash to identify the time when the droplet is at the target location. If there are ligament and satellites, the final trigger time should be long enough such that the ligament and satellites can reach the target location.
4) Increase the trigger delay of the strobe light flash from zero to the pre-determined time (T_f) to obtain the sequential image. The appropriate trigger delay increment can be adjusted to accommodate faster or slower drops, but 20 µs is typical.
5) Each sequential image is processed to measure drop trajectory and instantaneous jetting speed. Automatic image processing is recommended. From a binary image converted from a grey image, the maximum and minimum locations of the k^{th} droplet in the y direction, denoted as $P_k^{max}(t_d)$ and $P_k^{min}(t_d)$, can be obtained (see Figure A.5 and refer to Clause A.4). The superscripts max and min denote the maximum and minimum locations in the jetting direction, respectively. The drop trajectory was updated by adding the calculated maximum and minimum locations of each droplet, $P_k^{max}(t_d)$ and $P_k^{min}(t_d)$, respectively, to the graph before acquiring the next sequential image.

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6) The instantaneous jetting speeds of each droplet, $V_k^{max}(t_d)$ of the k^{th} droplet, can be obtained using the following relation:

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$$V_k^{max}(t_d) = \frac{P_k^{max}(t_d) - P_k^{max}(t_d - \Delta t_d)}{\Delta t_d} \quad (3)$$

   where Δt_d is the incremental time of trigger delay between the two consecutive images, and $P_k^{max}(t_d) - P_k^{max}(t_d - \Delta t_d)$ are the travel distance from the nozzle of the maximum locations of the k^{th} droplet during time duration Δt_d.
7) The calibration factor F (µm/pixel) should be determined at the optical magnification used by the drop analysis system to determine jetting speed (m/s) from Formula (3). The bottom locations of the droplet are used for the droplet location if the droplet has a long ligament. If Δt_d is too short, the jetting speed error due to image quality will be amplified. If Δt becomes large, a long-term average jetting speed is obtained instead of the instantaneous jetting speed at the target location.

4.5 Process for measurement of instantaneous jetting speed using double flash (method 4)

This process describes the measurement method for instantaneous jetting speed using the centroid of a single drop.

1) Commence printing with the desired specifications (frequency, ink selection, waveform, etc.). It is recommended to record the jetting conditions, as described in Clause A.6.
2) Specify the target location. The target location (stand-off distance) usually corresponds to the location S where the substrate media is located.
3) Switch to “double flash mode”, in which the LED is flashed twice for each droplet, showing the single drop in two different locations on the camera field of view.