MicroFab Technologies, Inc.

www.microfab.com

Ink-Jet Microdispensing

Basic Set-up

General Notice:

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Regarding Dispensing Device(s)

All dispensing devices are tested at MicroFab. Test waveforms are established for IPA and DI Water. If your dispenser does not function as expected, repeat these test conditions as described in the form included with each dispensing device. If the device does not dispense IPA or DI Water with the test waveforms, please contact MicroFab.

Cleaning procedures for MicroFab's dispensers can be found on the website at www.microfab.com

Warranty

There is no hardware associated with this document.

Limitation of Warranty

There is no hardware associated with this document.

General Safety Considerations

Warning	**The jetting device itself presents no general chemical hazard. However, when fluids are selected to be dispensed by the operator, appropriate safety measures should be followed as outlined in the selected material's MSDS.**
Warning	**Ink-jet dispensing with piezoelectric actuation requires an electrical signal. Standard safety procedures should be followed for the electrical connections. Before connecting / disconnecting the dispenser to the signal generator make sure that no electrical signal is produced.**

Introduction

This document is intended as a primer for first time users of ink-jet dispensing technology. It is written with the assumption that at least the ink-jet dispensers are purchased from MicroFab Technologies. The document discusses the needs of the "low temperature" dispensers and several approaches to fulfill them. The "high temperature" devices are only sold with their associated printhead and are not discussed here.

The set-up concentrates on "drop-on-demand" (DOD) operation, even though a set-up as described later on could be used for "continuous" ink-jet. In continuous ink-jet processes, drops are generated all the time and the ones that are used are selected from the stream of droplets. Drop-on-demand ink-jet can generate any desired number of drops (down to a single drop) whenever they are needed and thus provides better control.

A separate document describes in more detail the basics of drop generation, approaches in identifying appropriate operational conditions, and troubleshooting.

Components of a basic ink-jet dispensing set-up

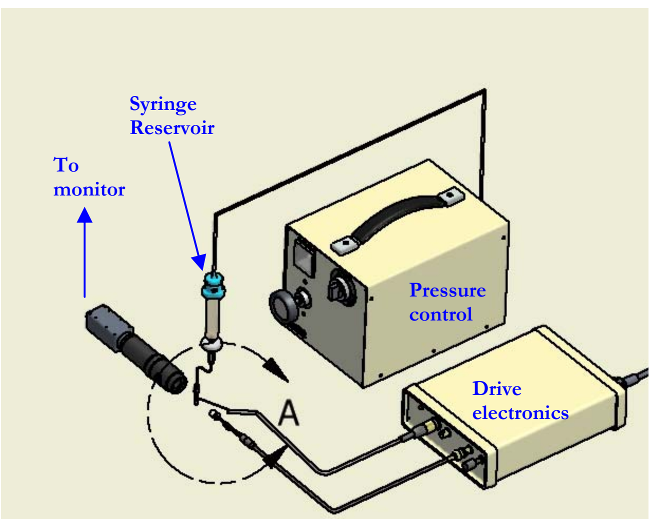


Figure 1. Components of ink-jet dispensing set-up

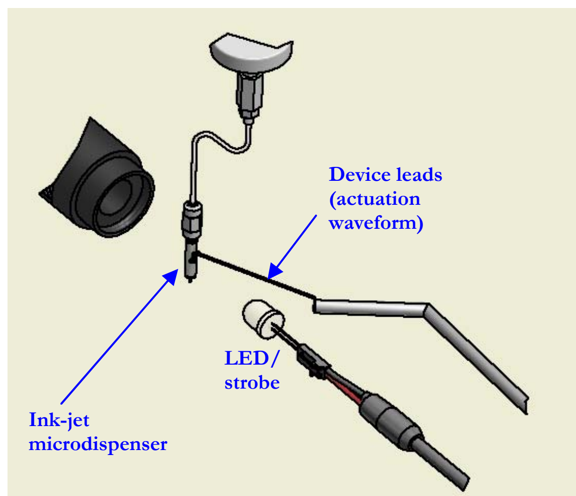


Figure 2. Detail of the area around the ink-jet microdispenser

The main components of a basic set-up for ink-jet dispensing are:

1. Ink-jet microdispenser or micro jet: piezoelectrically actuated droplet generator
2. Fluidics (tubing, connectors and reservoir): Feeds the liquid to be dispensed from the reservoir to the dispenser
3. Drive electronics: The ink-jet microdispensers discussed here employ a piezoelectric actuator to transmit the energy required by the drop generation. The drive electronics generate the electrical signal/pulse required to generate a drop.
4. Backpressure control & purging: Controls the pressure in the space above the liquid in the reservoir to a level that maintains the liquid flush with the orifice. By applying pressure to the reservoir, the solution is "purged" through the orifice. The purge is used to fill up the tubing

after filling up the reservoir and to eliminate air bubbles and contamination smaller than the orifice.

5. Observation camera & video monitor: Allows the visualization of the drop formation together with a LED that is turned on synchronously with the drop generation.
6. Mechanical mounting: Mounts the various components and aligns them with respect to each other.

In some implementations, the reservoir, fluid connections to the dispenser are all mounted into a subassembly which is referred to as a printhead. MicroFab offers several versions of printheads that account for various needs: minimization of the volume of the dispensed liquid, providing sufficient liquid for longer runs, inline filtering / heating / stirring of the dispensed liquid. More details can be found under Products/Printhead Assemblies on MicroFab's web site.

Dispenser

Construction, categories, and part numbers

The dispensers manufactured by MicroFab are actuated piezoelectrically. An annular piezoelectric (PZT) element, poled radially, is bonded to a glass tube with an integrated nozzle and orifice. The glass tube is mounted in a protective housing and, at the supply end, bonded to a fitting.

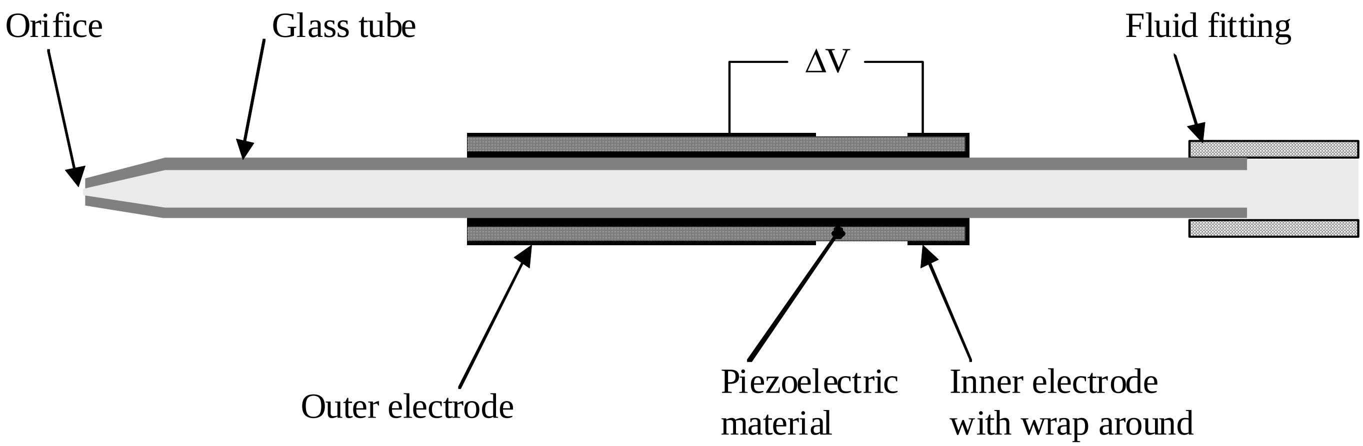


Figure 3. Schematic of MicroFab's glass dispensers

Figure 4. MJ-AB type device with wires and connector

The annular actuator has electrodes on the outer and on the inner surfaces. The inner electrode wraps around on the outer surface for easier electrical connection; a small region on the outer surface has the metallization removed to separate the two electrodes (Figure 3). Small gauge wires are soldered to the outer electrode and the (wrap around portion of the) inner electrode; the wires are loosely twisted and placed together in a connecter that matches the output cable of MicroFab's JetDrive™ electronics box.

The configuration of the dispensers or micro jets (MJ) is differentiated first by the type of fitting: AB – barbed (or slip on), AT – threaded (Minstac connection – small compression fitting by the Lee Company), ABL – barbed large, AL – Luer fitting. The AB and AT devices cab be manufactured with a protective feature (ABP and ATP respectively). More details on the various constructions can be found at Products/Microdispensing Devices/Low Temp. Devices on MicroFab's web site.

An example of the numbering for such a micro dispenser or micro jet is MJ-ATP-xxx, where the xxx is the orifice diameter in micrometers. The standard range of orifice diameter is 20-80µm for all devices except ABL devices where the range is extended up to 120µm. The part number MJ-ABP-075 refers to a micro dispenser with a barbed fluid connector, protected tip and an orifice with a 75µm diameter.

Principle of operation

When applying a voltage differential, the electrical field is generated between the inner and outer electrodes causing the piezoelectric actuator to expand radially (and contract axially) or, depending on the voltage polarity and poling, contract radially (and expand axially). The deformation occurs only along the portion where both electrodes are present, as the electric field is not generated in the region without electrodes and the wrap around region of the inner electrode.

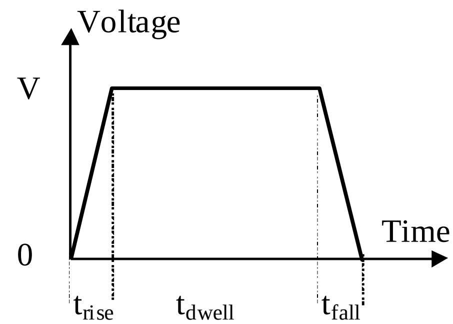


Figure 5. Simplest actuating voltage to generate a drop

The simplest actuation signal consists of a trapezoidal waveform that is applied, whenever a drop is desired, to one electrode while the other electrode is electrically grounded (Figure 5). Deformation occurs during the transition periods (rise and fall) and ceases during the constant voltage (dwell) period.

In MicroFab's configuration the inner electrode is grounded (blue wire) while the outer electrode (red wire) receives the actuation voltage.

During the rise time, the tubular PZT expands its circumference while becoming thinner and shorter. This fast deformation is transmitted through the epoxy bond to the glass tube and results in an outwards motion of the inner glass surface which produces a negative pressure (with respect to the equilibrium). The negative pressure travels in the fluid at the speed of sound along the glass tube in the form of an expansion acoustic wave to both the orifice and the supply end. The expansion wave is reflected as a compression wave (higher pressure than the equilibrium pressure in the glass tube) at the supply end and travels back towards the orifice. If the dwell time is selected to start when the positive pressure wave matches the piezoelectric actuator, the inwards motion of the inner glass surface reinforces it resulting in a faster and larger droplet.

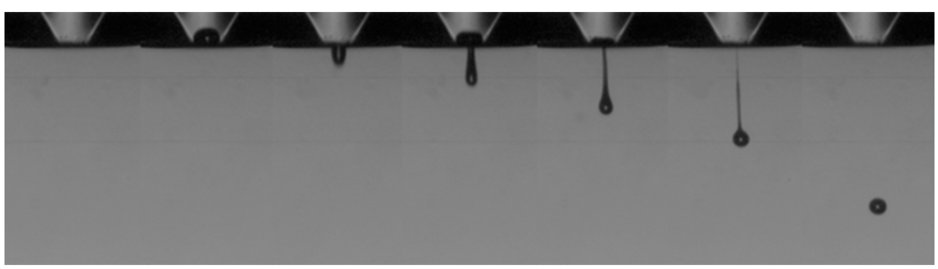


Figure 6. Drop ejection sequence of an organic solvent at 640Hz

Figure 6 shows the sequence of events at the orifice leading to the droplet formation starting with the equilibrium condition: fluid flush at the orifice (first image). In the second image, the fluid interface is withdrawn from the equilibrium position indicating the arrival of the expansion wave at the orifice. The third image is after the compression wave reaches the orifice causing the fluid to emerge. Another expansion wave reaching the orifice causes the fluid to pull back (images four and five) and to break off and leave the orifice (image six). The ejected fluid is pulled in a spherical drop by surface tension forces (image seven).

The images are obtained by a short pulse of light from an LED that is synchronized with the pulse generating the drop. By adjusting the delay between the actuation pulse and the pulse applied to the LED, the droplets are captured at different locations along the flight path.

Requirements for operation and observation:

- Proper operation requires that, when the dispenser is not actuated, the fluid is flush with the orifice (Figure 6 – left image). If the forces acting on the fluid at the orifice are not balanced, the fluid will either drip or withdraw in the nozzle. Both conditions result in a drop generation failure. The Backpressure control section below discusses two possible methods to maintain the fluid flush with the orifice.
- The operation is based on acoustics and wave propagation. The length scales and the speed of sound values result in timing in the tens of microseconds. Thus, the drive electronics should allow the adjustment of the timing in one microsecond increments or less.
- Observation of the drop formation is very important, especially when developing new solution formulations. The cameras, the LED and its driver are required to observe the droplets. To ensure sharp images, the pulse applied to the LED for illumination has to be very short (4-6μs) and, at the same time provide sufficient light at low frequencies.

Fluidics

If using one of MicroFab's integrated printheads, the specific implementation takes care of the reservoir and connection of the reservoir to the microdispensing device. This section only applies if the microdispenser was purchased separately and the user is setting it up on his own.

Tubing and connecting to the device

The MINSTAC fitted MicroJet devices have a male threaded end fitting that can be attached to tubing and fittings available from The Lee Company (www.theleeco.com).

A 062 MINSTAC Tubing Union (Part # TMUA3201950Z) can be used to interface the MINSTAC fitting on the MicroJet device with a MINSTAC Male Coupling Screw attached to Teflon tubing, as shown in the top image of Figure 7. Stocked pre-assembled tube sets having MINSTAC Male Coupling Screw on both ends of Teflon tubing (0.062" OD) are available (TUTC3216910L - 10 cm, TUTC3216915L - 15 cm, TUTC3216930L - 30 cm, TUTC3216960L - 60 cm).

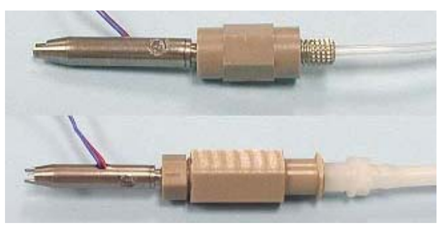


Figure 7. MJ-AT type device with a MINSTAC coupler. Top: MINSTAC 062 couple male to male using a union. Bottom: MINSTAC coupler male to Luer using an adapter

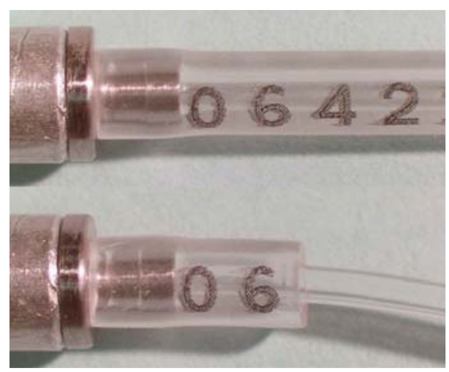


Figure 8. MJ-AB barb fitted device. Top: CFLEX tubing slipped over barb; Bottom: PTFE tubing slipped into CFLEX tubing slipped over barb

The 062 MINSTAC Fitting End Kit (Part # TMZA3202010Z) can be used to attach the male fittings to Teflon tubing in order to obtain custom lengths. Additional Teflon tubing can be ordered from Lee (TUTA3216930D - 10 feet).

Another option is to interface the MINSTAC fitting on the MicroJet device using the 125/156 MINSTAC Female Tube - Luer Adapter (TMRA9502950Z) with the 125/156 MINSTAC to 062 MINSTAC Adapter (TMDA3203950Z) to connect to male Luer fittings, as shown in the bottom of the Figure 7.

The barb fitting of MJ-AB MicroJet devices can be attached directly to C-Flex tubing, as shown in the top device in Figure 8. Another option is to slip the PTFE microbore tubing, 0.022 x 0.042 in (0.55x1 mm) E-06417-21 (Cole Parmer) into a small section (6.0mm) of C-Flex tubing, 0.031 x 0.094 in (0.7x2.3 mm) E-06422-01 (Cole Parmer) that has been slipped over the barb fitting on the device, as shown in bottom device in Figure 8.

The C-Flex tubing or PTFE microbore tubing can then be connected to the syringe barrel adapter described below by inserting the metal needle end of a female Luer fitted blunt needle into the C-Flex tubing (18 gauge needle part # 7018122) or PTFE microbore tubing (22 gauge needle part # 7018272) from Nordson EFD (http://www.nordson.com/).

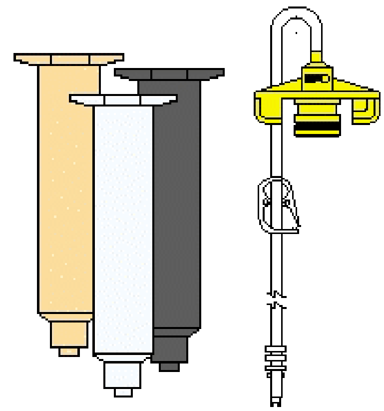


Figure 9. Left: Syringe barrel reservoir; Right: Syringe barrel adapter

The approach illustrated at the bottom of Figure 8 allows the use of higher resistance materials. For that configuration, use TYGON® Ultra Chemical Resistant Tubing EW-95630-00 (Cole Parmer) and then the same PTFE tubing described above.

Reservoir

The simplest reservoir is a syringe. A syringe barrel adapter assembly available from Nordson EFD (http://www.nordson.com/) (cat. # 7012341, 7012054, 7012339, 7012338) can be attached to a syringe barrel reservoir (cat. # 7012072, 7012094, 7012112, 7012134) to provide for a reservoir to the MicroJet device (Figure 9). The syringe barrel reservoirs and adapter assembles are available in 3cc, 5cc, 10cc, 30cc and 55cc volumes. The connection at the bottom is a Luer type fitting. Blunt needles from Nordson EFD (http://www.nordson.com/) can be used to connect to flexible tubing.

When using the AT microdispensing devices, the same type of fitting shown at the bottom of Figure 7 is used.

The syringe barrel reservoir and adapter assemblies provide the means to connect to the space above the fluid. This connection can be used for purging and maintaining the fluid flush with the orifice.

Filter

In some instances, a filter will eliminate particles that could clog the microdispensing device orifice. When using a syringe reservoir the easiest implementation is a 25mm syringe filter. Typically, a 5µm pore size is sufficient. The filter material needs to be compatible with the dispensed solution.

Drive electronics

Type of signals

The main function of the drive electronics is to generate the signal that is applied to the piezoelectric actuator. The simplest signal is shown in Figure 5 and is further referred to as "unipolar". More complex signals can include a negative pulse (or "echo") as shown in Figure 10. This signal is referred to as "bipolar". In general, V_0=0, but a nonzero baseline voltage can be employed as well. It is possible to have V_2=-V_1 or different.

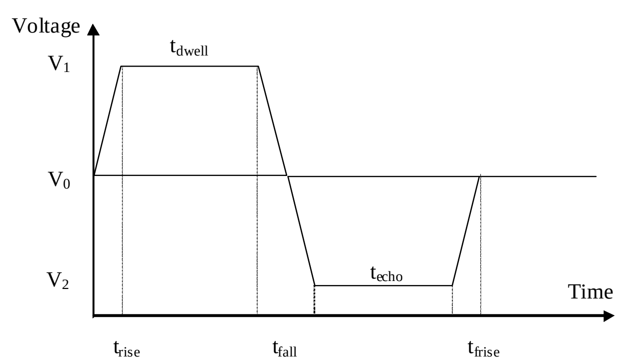


Figure 10. "Bipolar" actuating signal

More complicated signals are often used to increase the stability of the drop generation. For example, a "bipolar" (Figure 10) waveform can be employed to minimize the satellite formation or to get around the maximum positive voltage limitation. Other waveforms include additional points defining multiple voltage levels (Figure 11).

The complex waveforms are generally employed when dispensing more problematic solutions and/or to create droplets with a diameter smaller or larger than the orifice diameter; drop size adjustment through the waveform is often referred to as "drop size modulation".

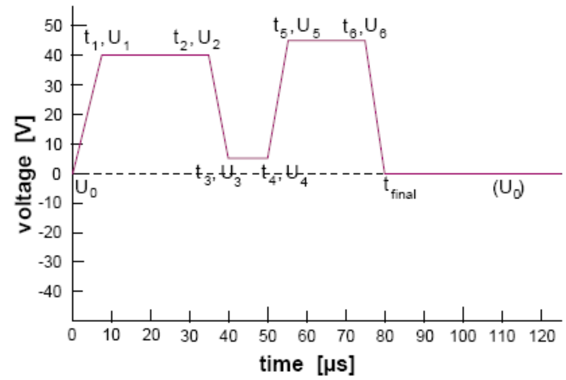


Figure 11. Arbitrary waveform defined by time-voltage pairs – six internal points

Values for the voltage and timings

The timing is determined by the length of the glass tube and the speed of sound in the dispensed solution. Based on the scales involved, the "dwell" and "echo" are in the tens (up to hundreds) of microseconds. The transition times "rise", "fall" and "final rise" are several microseconds long. For some fluids, the control the duration of the transition periods could increase the stability of drop generation.

When the polarity of the signal is respected (inner electrode - blue wire - is grounded and the outer electrode - red wire - receives the actuation voltage) there are limits on the positive side of the voltage. For AB, AT microdispensing devices V_1<70V. For ABL devices V_1<100V. Larger positive voltages could depole the piezoelectric material and cause it to not deform anymore under applied voltage differential.

The drive electronics should be able to produce transition times in the microsecond range with a capacitive load (the piezoelectric actuator) of ~2nF for AB and AT configurations and ~3.5nF for the ABL configuration.

The ability to adjust the actuating waveform should be at least 1µs for the timing and 1V for the amplitude.

Other requirements

In some instances, the dispense consists of several drops. The drive electronics should have the ability to create the desired number of pulses (down to one), in case a finite number of drops is desired.

For visualization purposes (see below the section related to observation), a short pulse (several microseconds long) synchronized with the drop generation needs to be created. That pulse is used to turn on an LED for a short period of time for stroboscopic illumination. The set-up should also allow the adjustment of the delay (Figure 12) between the actuating waveform and the LED/strobe pulse to "freeze" the droplet at various locations along the trajectory as shown in Figure 6. To avoid too much light at high frequencies of droplet generation, the number of LED pulses per actuating pulse or the duration of the LED pulse

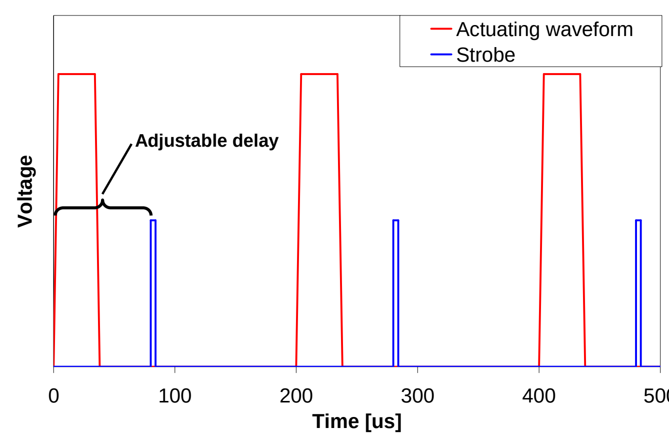


Figure 12. Actuating ("unipolar") signal and strobe signal

need to be decreased.

Some possible configurations for drive electronics

MicroFab's JetDrive™ provides the signals described above and allows the definition of an arbitrary waveform (Figure 11) with up to 12 internal points. In the associated control program (JetServer™ – see Figure 13 and Figure 14) the user can specify the actuating waveform, the drop generation frequency, and the number of drops to be generated. A secondary JetDrive™ output provides the signal used for stroboscopic illumination. The trigger can be either from the software or an external TTL pulse. Other features include computer controlled delay, adjustment of strobe lighting, running complex scripts for dispensing (start/stop, delay change, waveform change, frequency scans, etc.). If the software is combined with a computer relay switch, it is capable of driving multiple microdispensers. A separate actuating waveform is saved for each microdispenser. The capabilities are further discussed on MicroFab's web site under Products/Electronics & Software.

Alternatives consist of an arbitrary waveform (to achieve a flexibility comparable to MicroFab's JetDrive™) and an amplifier or a function generator (has limited shapes for the waveform) and an amplifier. In addition to these, separate electronics (with an adjustable delay from the pulse used for actuation) need to be used to generate the LED pulses.

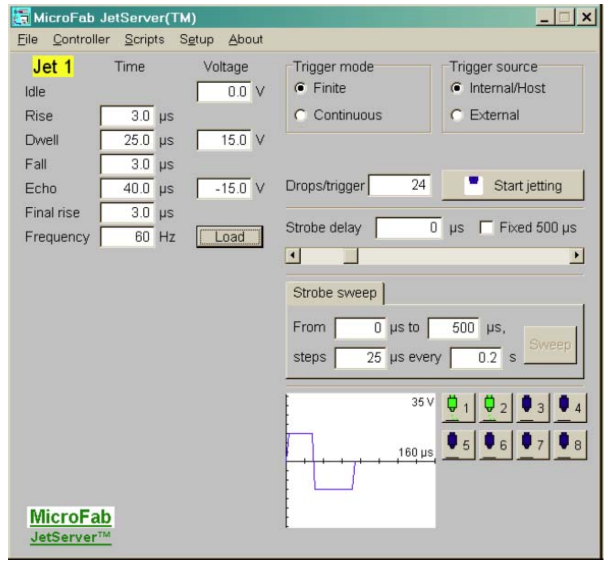


Figure 13. Screen capture of MicroFab's JetServer™ program – "bipolar" waveform.

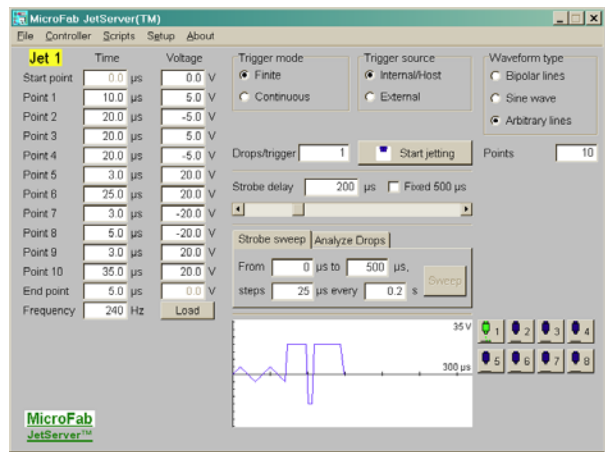


Figure 14. Screen capture of MicroFab's JetServer™ program – "arbitrary" waveform. The waveform in the example has a pre-actuation.

Backpressure control & purging

The need

If the liquid/air interface is withdrawn inside the tapered area of the nozzle, the actuation does not have enough energy to move the fluid forward and eject it from the orifice. If the liquid forms a "pool" on the orifice face (Figure 15) around the orifice, the energy input might be too low to form a drop. For a drop-on-demand ink-jet system to operate, the solution/liquid to be dispensed needs to be flush with the orifice. To maintain the fluid flush at the orifice during operation, the surface tension and hydrostatic pressure forces need to balance.

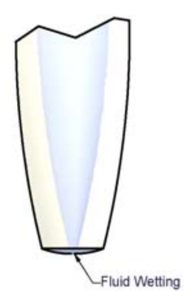


Figure 15. Liquid "pool" on the orifice face will generally not allow drop generation

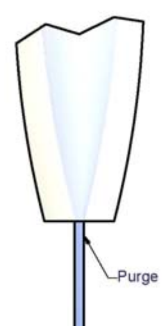


Figure 16. Fluid purged through the orifice by pressurizing the reservoir

Typically, maintaining the liquid interface flush at the orifice requires a negative hydrostatic pressure. While this could be achieved by arranging the fluid level in the reservoir to be below the level of the orifice, the reservoir is usually placed higher than the orifice in order to be out of the way. This is most often the situation when printing when the reservoir has to clear the substrate that is printed. When the fluid level is above the microdispenser orifice, vacuum is applied to the reservoir volume above the liquid to compensate the hydrostatic pressure from the fluid column.

If the reservoir (and liquid free surface) can be adjusted under the microdispenser's orifice, the reservoir volume above the liquid can be vented to the atmosphere; in this case, the liquid is maintained flush with the orifice by adjusting the reservoir level.

In addition to maintaining the solution flush with the orifice, it is practical to be able to apply pressure in the reservoir. The pressure either fills the tubing and the device after a reservoir fill-up, clears out contamination (smaller than the orifice) or air bubbles, or recovers dispensing in case there is a material dried out at the orifice. When pressure is applied, there is a stream of fluid that is ejected from the orifice (Figure 16).

Adjustment range

If the fluid is maintained flush with the orifice using the height of the reservoir, the reservoir and its adjustment range should allow a position where the liquid level is 2-3" below the orifice.

If the liquid is maintained flush with the orifice using vacuum, an accurate vacuum regulator should be employed. The vacuum would be several inches of water – the height of the fluid level above the orifice + 1-2" water column.

Applied pressure for purging depends on the orifice size and solution viscosity, but generally is between 10 and 25Psi and it should consist of clean and dry air or inert gases.

Some possible configurations for backpressure

The simplest configuration consists of a syringe reservoir mounted on a vertical post that can be lowered or raised. The syringe is vented during normal operation and is set at a height that makes the fluid is flush at the orifice - typically the fluid level is 1-2" under the orifice. For purging, pressure can be applied to the space above the fluid in the reservoir. This can be accomplished with a switch/valve that vents to the atmosphere.

In another configuration, the reservoir is fixed (can be above the orifice) and vacuum is applied to the space above the liquid to maintain the liquid flush with the orifice. This configuration requires a vacuum regulator with fine control. An accurate gauge makes it easier for the user to return to previously used operation conditions. Considering that the set point for the applied vacuum is in the range of 2-3" water column, the vacuum regulator and gauge should be capable of setting / reading within 0.1" water column of the desired value. Purging requires the pneumatics circuit described at the simplest configuration described aboe; in this case the switch needs to toggle the reservoir space above the liquid from vacuum/backpressure (during operation) to pressure (during purging).

MicroFab's basic pressure control unit incorporates the fine vacuum & pressure regulator, the gauge (vacuum & pressure), and a valve to switch between vacuum/backpressure to pressure for purging; adjustment and switching is done manually. Some models of the pressure control unit use a computer controlled pressure regulator and manual or computer controlled switching. The capabilities are further discussed on MicroFab's web site under Products/Pressure & Temp. Control.

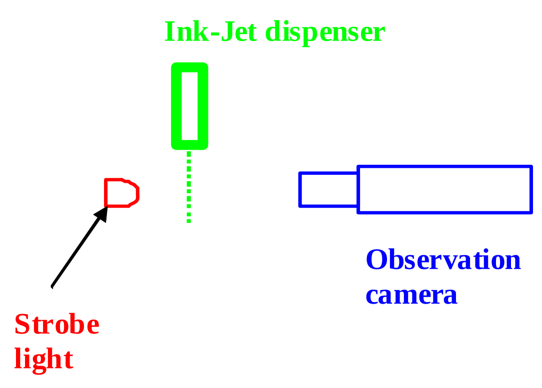


Figure 17. Placement of the LED with respect to the microdispensing device and the camera

Observation camera & video monitor

During drop formation it is useful to observe the drops being generated to get an idea of the drop characteristics (diameter, velocity and directionality) and for troubleshooting (identification of clogging or air bubble presence). High speed cameras could be used for this purpose, but they are expensive and require special illumination. Drop observation can be achieved in a more cost effective manner using synchronized illumination.

A light emitting diode (LED) is located on the opposite side of the camera with the dispenser in between (Figure 17). The LED is lit by a pulse synchronized (same frequency) with the drop generation (Figure 12). An adjustable delay between the actuation pulse for the drop generation and the LED pulse (Figure 12) "freezes" the drop along its path for observation. Figure 6 has a collection of images that were obtained during drop formation at increasing delay time between the actuating signal and the LED pulse.

This set-up allows the visualization of the drop as it is ejected from the orifice. Observation with this camera allows the operator to evaluate the drop ejection and to measure the drop characteristics (diameter or velocity). This measurement can be made in an automated fashion if image capture and analysis software is used in conjunction with the horizontal camera.

Stroboscopic illumination does not look at an individual drop, but at a collection of droplets that overlay in the camera view. If single drop characteristics are necessary, a high speed camera is required.

When setting up an observation system as described above, the magnification of the optics has to be such that the drops (average size around 50µm in diameter) are sufficiently large on the video display or the computer monitor.

The length of the pulse that turns on the LED has to be fairly short (preferred around 5µs and no larger than 10µs) to prevent "smearing" of the drop along the trajectory. The LED has to be selected to produce sufficient light for drop observation; this becomes critical at low operating frequencies. At high drop generation frequencies, there is generally too much light and this causes the drops to be "washed out". A means of reducing the amount of light has to be provided by either reducing the length of the pulse going to the LED and/or not sending the pulse to the LED for every drop being generated.

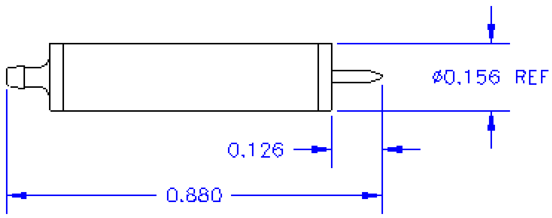
MicroFab provides both the camera and the associated optical elements. The JetDrive™ has a built-in output for the LED with the delay being controlled in the software and directly through a knob on the box. JetDrive™ comes with all the associated cables and the LED. Other related equipment includes a video capture board and an image analysis program that allow automatic measurement of the drop parameters.

Mechanical mounting

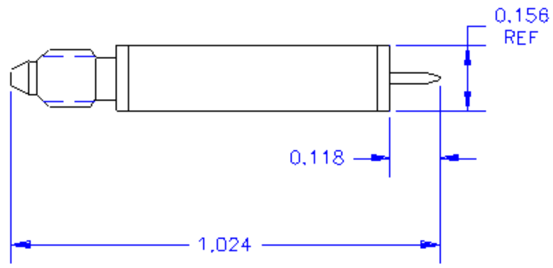
The low temperature devices in the MJ family (-AB, -AT, -ABP, -ATP, -ABL and -AL) can be mounted into MicroFab's printhead assemblies. Alternately, they can be mounted into customer designed fixtures. All low temperature devices are usually held by the cylindrical section in a small clearance hole using a nylon set screw to prevent deformation. A feed through for the wires must be a part of the mounting fixture. The wires come out at the center of the cylindrical section of each device type.

If -AL devices are connected directly to a syringe (their fluidic connection is a Luer fitting) it is recommended to hold the syringe barrel and not the dispenser to prevent damage due to the leverage introduced by the syringe. The ending on the protected tip devices provides the advantage of the conical reference surfaces for vertical and angular alignment. Finally, the -AT and -ATP can be mounted by holding the male Minstac union.

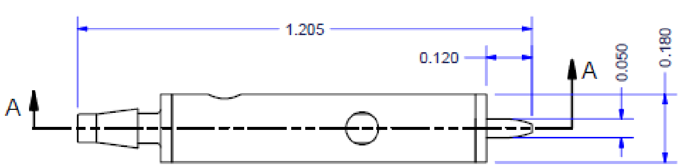
The basic dimensions (in inches) are included below.



MJ-AB



MJ-AT



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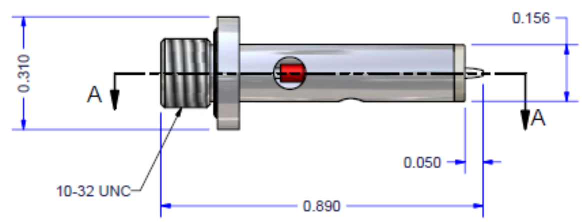
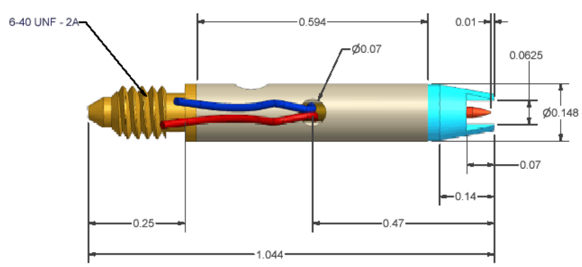


MJ-AL



MJ-ATP

The mechanical parts and their assembly have to allow the alignment of the camera, LED and dispenser. Because some of the LEDs have a small cone angle and because at the required magnification the entire field of view is only couple of millimeters square it is important to have the means for precise adjustment.

For the camera mount, the location is determined by the camera-optics working distance. If the camera does not have a focus adjustment, the camera should be adjustable along the LED – device direction.

If the backpressure is set by adjusting the reservoir height, the mechanical features have to provide for it. A method of reading the height of the liquid level under the device tip should also be devised.

Beyond dispensing

The set-up described above consists of the basic equipment that will allow the user to generate drops, to observe the drop formation and to optimize drop generation. It can be used to evaluate various solutions for dispensing, which is necessary during the formulation of ink-jettable materials.

In most cases, the generated droplets need to be deposited on a substrate that has to be moved under the dispenser. For such applications, the user has to provide at least a manual stage (for printing along a line) or two manual stages that are mounted orthogonally (for printing in two dimensions). A better approach is to have computer controlled stages where the positioning is set by a control program. If the user develops the motion hardware and software, the JetDrive™ box can be controlled through a RS232 interface through a command set that is available from MicroFab. These options work when the deposition on the substrate requires only relative alignment (of the dispense locations), but precise alignment with respect to the substrate is not needed.

For accurate placement with respect to existing features on the substrate, a vertical camera is required. MicroFab's systems (under Products/Complete Systems) employ such a camera and the associated functions for alignment. When selecting the image analysis option, the alignment process can be set such that alignment marks are picked up automatically. The printing system provide built-in printing patterns like lines, borders, arrays, arrays of arrays, combinations of circular/elliptical arcs and straight lines. Complex patterns can be generated using scripts to combine the basic patterns and/or defining discrete points.

Contact

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