# Micro Dispensing Comes of Age

***With semiconductor components and packages continuing to shrink in size, dot diameters of 10 mils and under mandate an "Integrated Engineering" approach to the design of dispensing equipment.***

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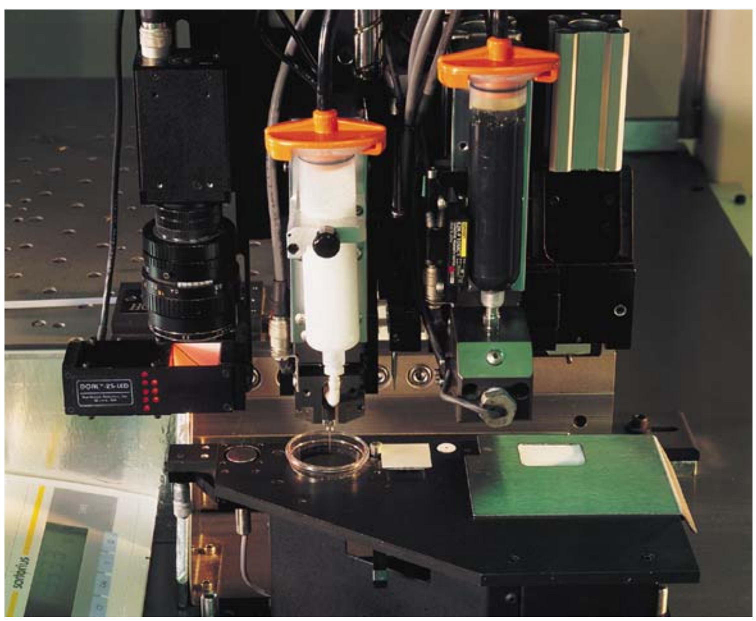
As the technology for electronic products such as cell phones, pagers, and hand-held computers continues to evolve, flex circuits and printed circuit boards (PCBs) within these products are becoming more densely populated with faster and ever smaller chips and packages. While designers look for ways to accommodate circuitry on shrinking real estate, manufacturers face the particular challenge of depositing solder paste, conductive epoxies, and underfills in extremely precise patterns for mounting ultra fine pitch leaded devices, ball grid arrays (BGAs), chip scale packages (CSPs) including micro BGAs and flip chips, and direct chip attach (DCA) components.

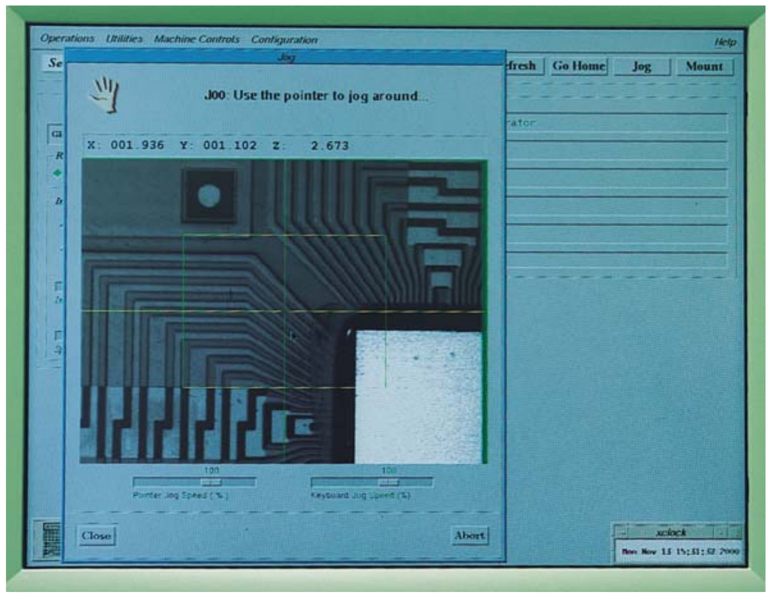


This paper considers the technical challenges associated with dispensing small, precise volumes of solder paste and epoxies in electronics manufacturing. "Integrated Engineering" has become the means of achieving the precision required to dispense materials for assembling leaded and area array "micro" components on substrates. This product engineering concept takes into account the cumulative tolerances of the primary elements of the dispensing system -- pump, platform, and controlling software -- as they affect the end result.

### *Integrated Engineering*

In designing and developing liquid dispensing equipment for electronics assembly, manufacturers set objectives in terms of a number of parameters, including speed in dots per hour (DPH), flexibility, accuracy and repeatability, and throughput. Such parameters and other relevant factors (benchtop vs. floor model, platform size and stability, degree of automation, presence or absence of heat, type of conveyor, etc.) are decided upon relative to the targeted price range and intended use of the product.

The heart of any system is the pump; for this reason, the performance of a dispensing system is typically measured by the capabilities of the dispensing heads. Beyond that, manufacturers typically "build in" as much platform and software technology as is permitted by cost and motivated by competitive products on the market.




Precision dispensing of small dot diameters and small volumes of material mandates a different approach. The accuracy and repeatability required for Micro Dispensing* can only be achieved by a system design that takes into account the accumulation of tolerances (known as "error stackup") attributable to the mechanical and electrical attributes of the platform. Also essential is the software that controls dispensing and gantry operations, and compensates for deviations in motion and speed.

While tolerance accumulation is relevant in liquid dispensing for mounting conventional SMT (surface mount technology) devices, such as QFPs and SOICs, dot diameter and X-Y accuracy become more critical as component sizes become smaller.

Simply put, there is less margin for error. An in-tolerance X-Y deviation by the platform, for example, added to an in-tolerance theta deviation by the dispensing head could well result in a solder dot not being accurately deposited on its intended pad.

In developing a machine for precision dispensing of dots with diameters of 10 mils or less, the entire system must be re-engineered by designing and building subassemblies that collectively meet performance objectives and specifications, and by

* For purposes of this paper, Micro Dispensing is defined as dispensing of solder paste and conductive epoxies with dot diameters of 10 mills or less.

incorporating closed-loop feedback software. Subassemblies include pumps and motors, dispensing needles, lead-screws, linear slides and rails, and even the frame itself. This is *Integrated Engineering*.

## *Material and Process Parameters*

Precision dispensing of solder paste and epoxies depends on various parameters, including the composition of the material itself. In electronics assembly, liquid dispensers are used in batch or in-line configurations to deposit solder paste and epoxies on substrates. Epoxies may be non-conductive for attaching components, or they may provide thermal or electrical conductivity, depending on the type and loading of metal particles in the binder, and their physical structure (flakes vs. spheres).

Material parameters for dispensing are listed in Table 1. Viscosity is dependent on both the epoxy binder and the metal mixed into the epoxy. Characteristics such as the ability of the material to flow under pressure, and for solder pastes, to "wet" the lead or solder ball, have a bearing on the amount deposited and the quality of the interconnect. Other variables, which may be classified as *process* and *tool* parameters, are identified in Table 2. Of the parameters in Table 2, the distance of the needle tip above the substrate is an essential factor in achieving the proper diameter-to-height ratio in a dispensed dot (Figure 1). In general, for low viscosity materials, the diameter-to-height ratio should be about 3:1; for high viscosity pastes, 2:1 (Figure 2). Proper distance above the substrate is easy to ensure with the use of a dispensing needle equipped with an offset foot (Figure 3). Where a footed needle cannot be utilized, such as area fills, dispensing near package walls, or in applications with high component density, it is important to have a high degree of Z-axis accuracy. Other process and tool parameters are discussed on the following page.

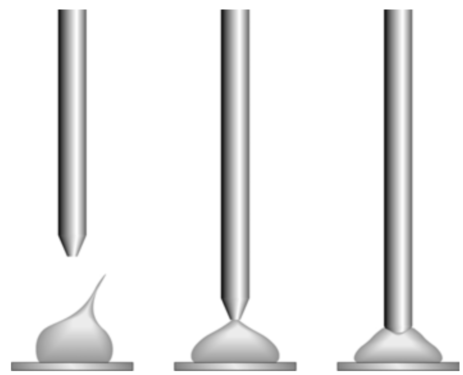


**Figure 1.** Needle tip height above the substrate determines the diameter-to-height ratio of the dispensed dot. A needle tip too far away from the surface can cause slumping of the dispensed material. A needle tip too close to the surface can cause tailing and bridging of the material, as well as carry-over to the next dot location.

**Table 1**
**Material Parameters in Dispensing**

| | |
|---|---|
| Drying/aging properties | Temperature |
| Flow characteristics | Viscosity |
| Homogeneity of mixture | Wetting characteristics |
| Presence/absence of air | |

**Table 2**
**Process/Tool Parameters in Dispensing**

| | |
|---|---|
| Tack time | Pump control accuracy |
| Needle distance above substrate | X/Y accuracy and repeatability |
| Needle ID (inside diameter) | Z-axis accuracy and repeatability |
| Needle tip design | |

## *Design Features for Optimized Micro Dispensing*

In developing a liquid dispenser for Micro Dispensing applications, state-of-the-art advancements in pump technology enable the deposition of extremely precise dots of material with diameters of 10 mils or less. As mentioned under “Integrated Engineering”, however, accuracy and repeatability can only be assured through design considerations involving the entire dispensing system. A system able to meet the challenge of assembling the smallest available components on substrates and in packages is described below.

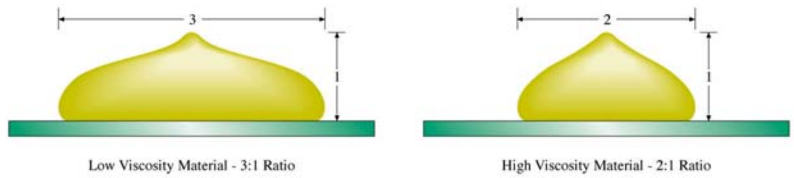



**Figure 2.** The diameter-to-height ratio for a low-viscosity material can be as much as 3:1; for a high-viscosity as much as 2:1.

**Pump Technology and Dispensing Needles.** The process of dispensing involves the displacement of fluid material, often through a syringe, by either air pressure or mechanical means. In the recent past, time/pressure pumps were the dominant type of pump on dispensing machines. These pumps, which can still be found on machines today and are the popular method of hand-held dispensing, rely on pulsed high-pressure air to provide the force on a plunger to move the material through the syringe. With such systems, the material tends to heat due to pulsing of the air; accordingly, viscosity changes; separation of solder and flux (or filler and binder in the case of epoxies) can occur; and the volume dispensed from a single tube can vary over time.

While a number of different pump designs exist, dramatic improvement in accuracy and repeatability in material deposition has been achieved with the development of the rotary auger pump. A dc motor drives an Archimedian screw that rotates in a cartridge. A low-pressure air supply is used to maintain a steady flow of solder paste or epoxy into the pump. The advantage of this design is two fold: material is delivered through the cartridge by the auger in precise amounts; and, because the temperature of the material is stable (there is no heating of the material due to pulsing air), viscosity is more consistent.

The disadvantage of this type of pump has to do with the level of control afforded by the dc motor. When dispensing is to occur, the pump motor “ramps up,” and at the end of the cycle, “ramps down.” Depositions may vary from cycle to cycle due to the inability of the dc motor to precisely control the rotation of the auger as it adjusts to variations in material viscosity.

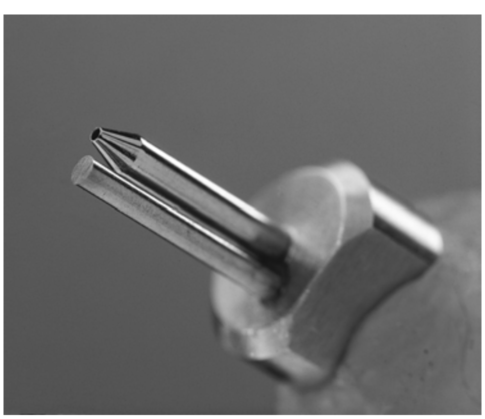


**Figure 3.** Needles with an integral foot ensure the proper height above the substrate during dispensing.

An advanced type of pump, the Micro Dot Valve shown in Figure 4, overcomes the limitations of the conventional rotary auger pump. The fully programmable pump augments its brushless servo motor with an encoder that precisely controls the rotation of the auger. The encoder provides 57,000 counts per revolution. In other words, a single 360° turn of the auger is segmented into 57,000 portions of a revolution to provide unprecedented accuracy.

For example, the Micro-Dot Valve, dispensing a fine pitch eutectic (63/37) solder paste through a 28-gauge needle with a standoff of 0.003" (0,076 mm), is capable of achieving precise dot diameters of 10 mils.

**Design Features.** The auger and cartridge liner in the pump are constructed of carbide steel, selected because it is almost frictionless when running carbide in carbide. Another notable feature is the "soft-mounted" syringe, designed to reduce the settling, or compacting, effects on material that can occur during repeated up and down Z-axis movement of the dispensing head.

Also important to Micro Dispensing is the needle installed in the dispensing head. In fact, the most significant barrier to dispensing small dots is clogging of the needle. The Micro-Dot Valve employs uniquely designed, highly polished stainless steel needles with a chamfered tip. The chamfer reduces the surface tension between the needle and the material at the point of separation. As a result, the solder paste or epoxy is less likely to cling to the tip, resulting in tailing and bridging as the needle lifts away from the dispensed dot. The polished surface inside the needle and its single piece extrusion (as opposed to rolled tubing) create the least amount of surface interference as the material flows through the needle.

**Platform and Frame.** While pump technology ensures the precise and repeatable dispensing of a particular dot diameter and volume of material, the platform ensures the accuracy of the dot placement in X, Y, and Z. State-of-the-art design mandates high-precision, stainless steel, anti-backlash ball screws and stainless steel linear bearing slides and rails. However, additional improvements are necessary to achieve the desired accuracy for Micro Dispensing. Notable innovations include a gantry manufactured out of cast MIC-6 aluminum, the installation of encoders on the motors with a zero-backlash coupler, and the use of a special composite material for the frame. As a result, positional accuracies within ± 0.0015" (0,0381 mm) can be consistently achieved.

Each innovation serves a specific purpose. The molecular structure of the cast aluminum is such that the gantry cannot warp under use to any measurable degree. By utilizing encoders and zero backlash couplers, the dispensing system will know exactly where the gantry is, as opposed to predicting where it will go. Finally, the composite material consists of 90% quartz and 10% polymer. For this reason, and also because of its weight, a machine of this type is effective in damping shock and vibrations attributable to the X-, Y-, and Z-axis motion of the dispensing heads.

**Software Control.** Software is also essential to precise and repeatable performance. In the ideal system, the dispenser is programmed and controlled with a real-time, multi-tasking software system that provides process verification via closed loop feedback. A "Windows" type of program is easy for engineers developing programs for a variety of applications. Software that provides material, valve, and shape libraries; inter-facility communication via host computer; production data logging; user password protection; and simplified user interface is also crucial.

Contour Mapping®. Integrated design for micro dispensing solder paste and epoxies culminates with the manufacturer's *Contour Mapping® System*. Each dispenser is calibrated before being shipped to ensure against error stackup. In addition, a mapping kit is made available to customers to ensure the highest performance and precision under use.

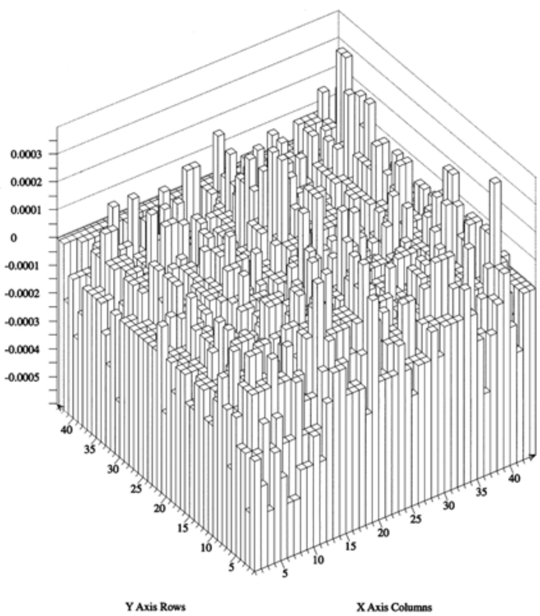



**Figure 4a.** Contour Mapping® significantly reduces maximum X and Y deviations, as can be seen from before (above) and after (below) mapping results.

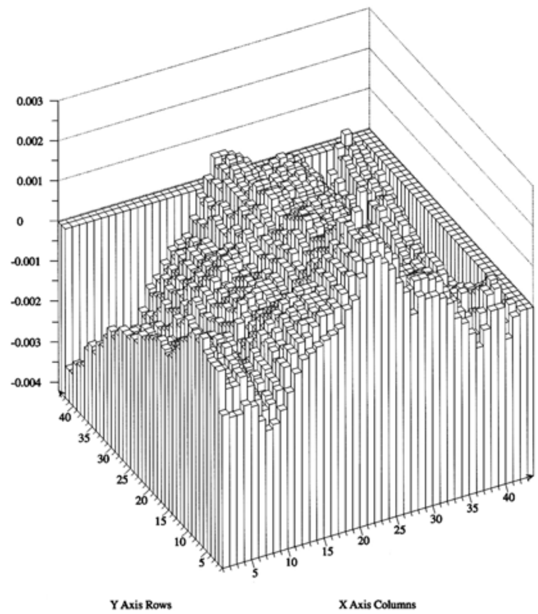



**Figure 4b.** Raw maximum X and Y values after Contour Mapping® procedure.

The Contour Mapping® Kit consists of a NIST traceable glass plate with etched 50 mil dots spaced in 0.5" (12.7 mm) increments in a precise X/Y grid, software to run the program, and mounting hardware. Glass is used for the plate because, unlike metal, its neither expands nor contracts with ambient temperature differences. Figure 4a shows the raw maximum X and Y values for a typical application before mapping, while Figure 4b shows the results after mapping.

***Summary***

With the increasing emphasis on smaller components and densely packed substrates, precise dispensing of solder paste and conductive epoxies for electronics assembly is being severely challenged by equipment capabilities. For liquid dispensers, an accurate pump is not enough; instead the entire dispensing system must be engineered to accommodate the accumulating tolerances attributable to pump and platform mechanics and other factors. The process of *Integrated Engineering* assesses all manufacturing and performance parameters so that dispensing accuracy and performance can be viewed in light of all system variables.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