本文说明集成装载重量管理系统的使用，以测量、调整和确保点胶泵输出特定目标重量的供给量。在选择和使用环氧树脂点胶机时，大部分重点放在泵技术上。三种方法广为接受：时间/压力法、螺旋钻泵法和正排量泵法。这些方法具有精确的短期可重复性，但快速容易地测量并调整称为“过程对中”的能力最终将保持过程的控制。系统不仅要保证给料量的变量尽可能小，而且供给材料的平均量必须同目标相符。

An On-Board Mass Calibration System for Liquid Encapsulation

Thomas Karlinski

A case study shows pump output tolerances of 1% can be achieved.

In the selection and use of dispense platforms, much emphasis is placed on the pump technology. For dispensing epoxy, three methods have gained wide acceptance: time pressure, auger and positive displacement. For whatever technology chosen, the process engineer will often focus on short-term pump repeatability as a major equipment selection and qualification criterion. Good short-term repeatability is necessary but not sufficient to meet performance expectations: It gives only a “snapshot” of pump capability. Rather, the ability to quickly and easily measure and adjust the process centering over time will ultimately keep the process in control and producing good parts. Not only must the system dispense with as little variation as possible, but the average amount of material dispensed must match the target.

First, a brief description of process capability. The output of a stable process, such as dispensing specific volumes of epoxy for flip-chip underfill, follows what is called normal distribution. This bell-shaped curve is described by two process parameters, the process average and the process spread, the naturally occurring deviations from

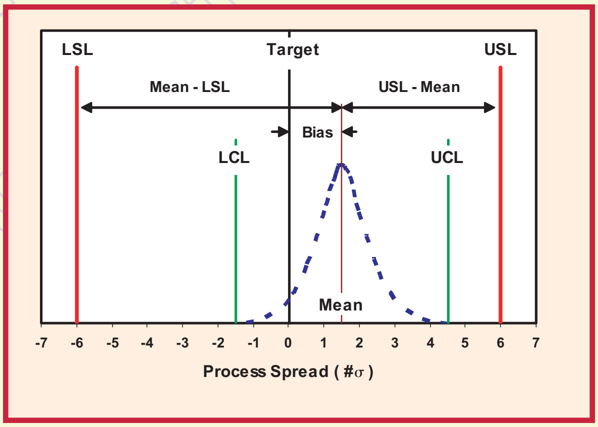

FIGURE 1: The relationship between variables of Cpk.

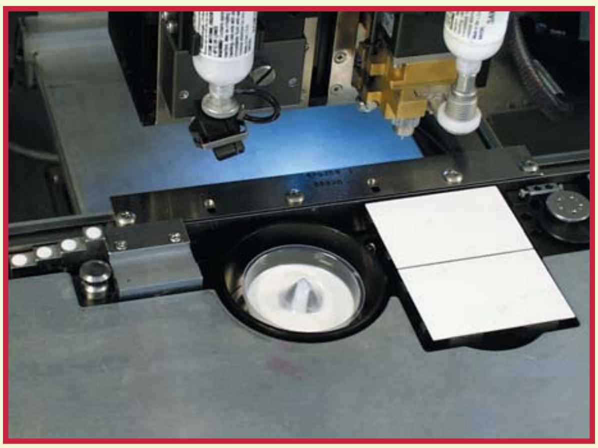

FIGURE 2: WMS balance, with covers removed.

average, described by the standard deviation (σ). Standard deviation relates how often a measurement is expected in a range of deviations around the average. For a normal process, 99.73% of all measurements are expected within a range of ± 3σ around the average, the LCL and UCL.

The measure of process capability compares this distribution to the specific product requirements called the upper and lower specification limits, USL and LSL. In the example of a flip-chip process, these limits should relate to the range of epoxy weights (volume), centered around a target weight, that will provide the right amount of epoxy coverage under and around the chip. The statistical index measuring this capability, called Cpk, incorporates the proximity to target as well as the process spread in a single metric. CpK is defined as

$$Cpk = Min\ \{(Mean - LSL)/3\sigma,\ (USL - Mean)/3\sigma\}$$

Figure 1 shows the relationship among these variables.

As the process mean deviates from the target, one of the two ratios becomes smaller while the other increases. Better (larger) values can be obtained by minimizing the "targeting" error or reducing the process spread. Cpk values of greater than 1.67 are typically required for today's manufacturing processes.

When the process mean equals the target, both ratios are the same and are the largest possible value. This will yield the largest possible Cpk for a given process spread.

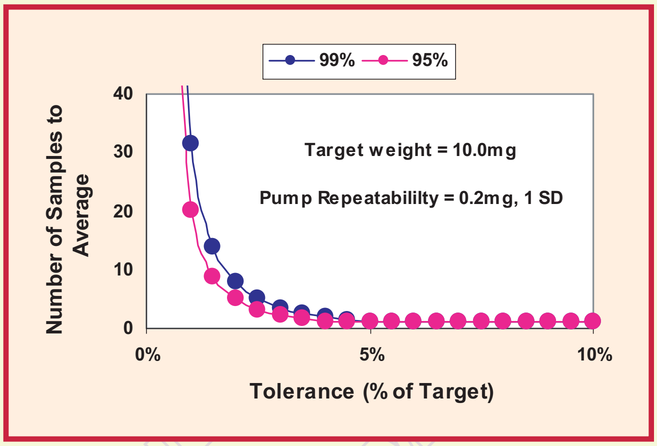

FIGURE 3: Required sample sizes for 99% and 95% confidence intervals.

Adjusting the mean to equal the target is the function of the weight measurement system.

The weight management system (WMS) (**Figure 2**) is a Sartorius balance (80 mg range, 0.1 mg readability, settling time ~2 sec.) on a novel dispenser and is accessible by either dispense head on a two-pump system. It uses a technique called pattern weigh technology to dispense the pattern in exactly the same way it would be done on product but without moving in x and y. The advantage is that while calibrating, the pump will exhibit the same linear and nonlinear dispense rate characteristics experienced during a typical dispense cycle. Acceleration and deceleration of physical pump components as well as material inertia result in brief periods of ramping dispense rates at the beginning and end of each pattern. As dispense times lessen, these rate changes have a larger influence on final dispense weight. This approach contrasts the calibration scheme that measures and maintains only the steady state dispense rate of the pump.

Since the x-y gantry motions (not z) have been disabled during calibration, the epoxy must be removed from the needle tip in a manner that closely mimics the real process. For this purpose, the

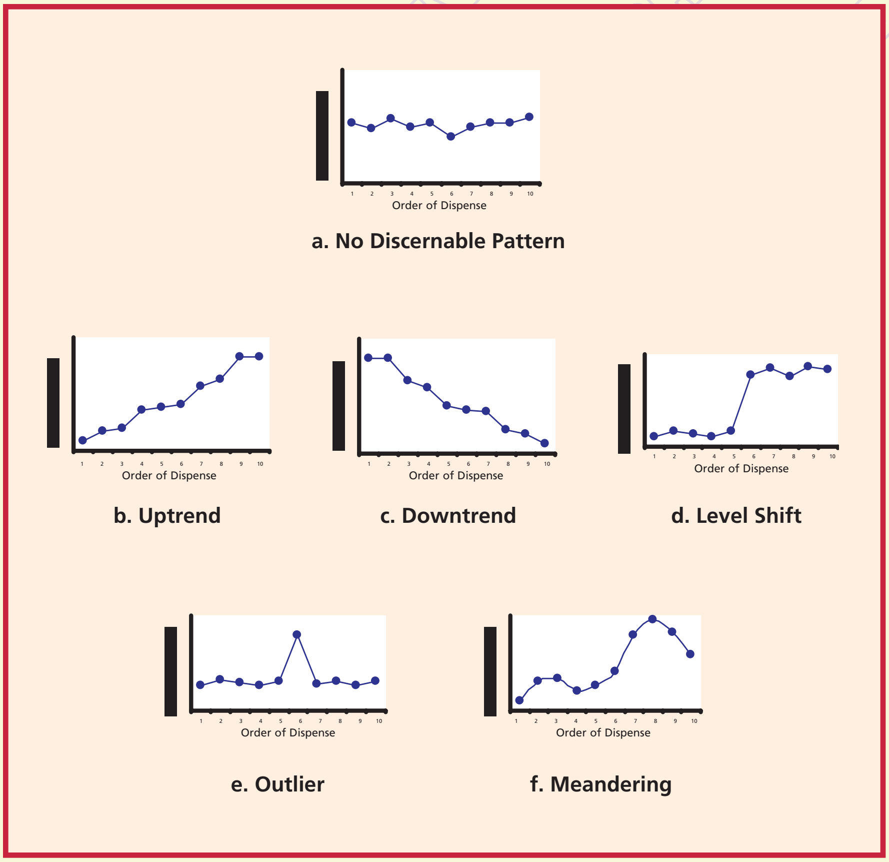

FIGURE 4: Patterns of process variations.

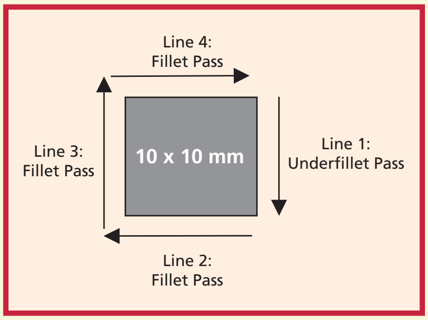

FIGURE 5: Underfill test program.

	Auger Pump	Piston Pump
Needle Gauge	22	22
Auger Lift	0.005"	NA
Syringe Air Pressure	15 psi	15 psi
Pump Temperature	40°C	40°C
Pump RPM		
Line 1	750	10
Line 2-4	375	5
Program Line Width		
Line 1	397	350
Line 2-4	34	30

TABLE 1: Test Parameters

weighing pan of the scale has been modified to hold a plastic cup formed with a cone rising at the center. When dispensing, the needle is positioned just above the peak of the cone at a height similar to that in the actual dispense program. The steeply sloping surface of the cone permits material to fall away from the needle tip.

The line width variable, LW, associated with each line determines how much material will be deposited. The units of this variable are degrees of pump rotation per mm of travel. A LW of 360° means that for every mm of line length, the pump rotates one complete revolution. Increasing this value will deliver more epoxy per mm of line and, conversely, reducing the LW will decrease the amount of material. This variable is used to adjust the amount of material dispensed.

The algorithm to adjust the weight is a simple iterative approach assuming a linear response between LW adjustments and the mass dispensed. The pattern is dispensed once to measure and compared to the target. If not within tolerance, an LW adjustment is made and the pattern is weighed a second time, comparing the new result to the target. The algorithm will iterate in this manner until the measured weight is on target within tolerance. The LW variable is then updated in the program. If the WMS fails to find target within six iterations, operation is interrupted and an error message displayed.

Calibration Parameters

Reliable calibration depends on the pump's basic capability and the proper selection of values for the target, tolerance, sample size and frequency.

Target selection. Target values can be estimated from calculations of volumes using nominal dimensions for the component or assembly package being considered. In practice, the estimates are used as a starting point. Target volumes are verified by dispensing test samples and analyzing the finished product.

Tolerance and sample size. The calibration algorithm attempts to converge the program line widths until the measured weight matches the target weight. The tolerance parameter determines how closely these two values match. Remember that the process average value is being adjusted during this operation. The tolerance value is the acceptable error or uncertainty associated with the targeting process. It is expressed as a percentage of the target value. As **Figure 1** shows, the tolerance value corre-

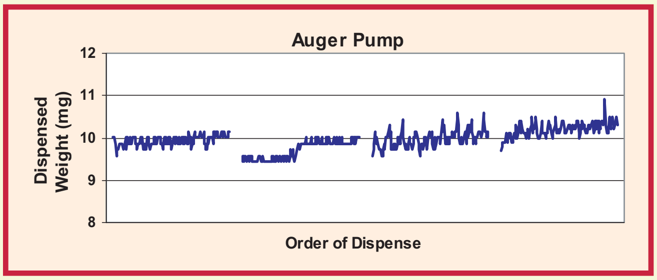

FIGURE 6: Results of augur pump in screening run.

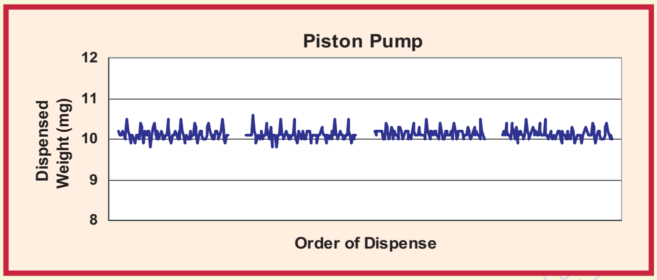

FIGURE 7: Results of piston pump in screening run.

sponds to the maximum acceptable bias or centering error. It does not represent the USL/LSL nor the 6σ distribution of dispense values.

If the tolerance is the maximum acceptable error for that measurement, then the following formula defines that tolerance in terms of the sample size (N), process standard deviation (S[st]) and U(a/2). U(a) relates to the confidence level for an alpha error; i.e., making the mistake of judging the average within tolerance when it is in fact not.

*Tolerance = [U(a/2) * S(st)] / SQRT(N)*

Rearranging this formula, the minimum required sample size can be computed:

	Auger Pump	Piston Pump
Process Std. Deviation	0.17 mg	0.13 mg
SS for 1% Tolerance	23	13

TABLE 2: Process Variables (est.)

*N = {[U(a/2)]^2 * S(st)^2} / (Tolerance)^2*

Consider the case of an underfill dispense with a target weight of 10.0 mg and USL/LSL values of 11.0 mg and 9.0 mg, respectively. **Figure 3** plots the sample size required for a 99% and 95% confidence interval. These data reveal that as the tolerance value decreases from 5% to 2%, the number of samples per measurement gradually increases. For tolerances below 2%, the number of samples required climbs steeply.

At a confidence limit of 95% and n = 1, the operator can only be confident that the real average is within the interval defined by the measurement ±4.0% (or in this case the ±0.4 mg) 95 of 100 times. Conversely, five times out of 100 the real average will be outside these limits. A 99% confidence limit requires that 20 samples be taken for every measurement to be confident in a 1% tolerance.

Failing to match the sample size to the tolerance may result in false positives.

Frequency. Having defined the target weight, sample size and tolerance, one variable remains: frequency. How often is weight calibration necessary? No specific rules to exist, but in general the frequency should maximize the likelihood of observing changes to the average weight. The WMS allows the operator to schedule calibration by time or number of units dispensed.

Dispense trials offer insight into the short- and long-term dispensing characteristics of various pump options and will help define this frequency. Different patterns of process variation may be seen in the dispense results. The more common patterns are illustrated in **Figure 4.** Of these, only the uptrend and downtrend patterns can be predictably controlled with periodic weight calibration. The other patterns represent random events that cannot be anticipated. In all cases, the cause of such patterns should be identified and eliminated, if possible.

Dispense Trials

Trials were conducted to determine the efficacy of the WMS to target and maintain dispense weights over a five-day period. Both auger and piston pumps were used. A simple underfill test program was created around a 10x10 mm chip (**Figure 5, Table 1**). Total target weight for this chip was set at 10.0 mg. To facilitate data collection, all dispensing was done directly on the Sartorius balance and measurements recorded to the SPC data log. Loctite 3563 underfill epoxy was used throughout the trials.

Screening runs. Short-term data were collected to estimate process repeatability, sample size and reveal patterns which might indicate an out-of-control dispense process. The pump was cleaned and

Short-term pump repeatability gives only a snapshot of pump capability.

Run Calibration DataMean Data: Auger Pump							
	# Iterations	Result	1	2	3	4	Total
Day 1	4	9.94	10.11	10.12	10.13	10.13	10.09
2	2	10.07	10.01	9.70	9.87	9.79	9.89
3	4	10.06	10.21	10.19	10.15	10.13	10.15
4	1	10.03	10.13	10.09	10.03	10.06	10.07
5	2	10.02	10.09	10.03	10.03	10.00	10.03
						Grand Mean	10.04
Run Calibration DataStandard Deviation Data: Auger Pump							
	# Iterations	Result	1	2	3	4	Total
Day 1			0.15	0.11	0.12	0.11	0.12
2			0.08	0.10	0.05	0.06	0.14
3			0.09	0.06	0.07	0.07	0.08
4			0.05	0.05	0.11	0.06	0.08
5			0.06	0.08	0.07	0.07	0.08
						Grand SD	0.15

TABLE 3: Augur Pump Test Results

Run Calibration DataMean Data: Piston Pump							
(mg)	# Iterations	Result	1	2	3	4	Total
Day 1	2	9.99	9.95	9.95	9.94	NA	9.94
2	3	10.03	10.04	10.02	10.04	10.05	10.04
3	1	9.99	9.91	9.92	9.95	9.92	9.93
4	2	10.00	9.97	9.98	10.00	10.01	9.99
5	1	9.95	10.01	9.99	10.00	10.05	10.01
						Grand Mean	9.98
Run Calibration DataStandard Deviation Data: Piston Pump							
(mg)	# Iterations	Result	1	2	3	4	Total
Day 1			0.13	0.13	0.14	NA	0.13
2			0.15	0.09	0.17	0.12	0.13
3			0.20	0.11	0.15	0.11	0.15
4			0.12	0.10	0.08	0.12	0.11
5			0.13	0.17	0.17	0.16	0.15
						Grand SD	0.15

TABLE 4: Piston Pump Test Results

primed with epoxy. One hundred measurements were collected over 15 minutes. This was repeated three times. The same syringe of epoxy was used for all four runs. Pump results are shown in **Figures 6** and **7**.

The process variation is slightly larger for the auger pump due to slight upward and stepwise variations in the data. These excursions are on the order of 0.5 mg. Data for the piston pump showed no discernable pattern variations. From these data, variables were estimated per **Table 2**.

Targeting tests. Each day the pump was cleaned and maintained according to the manufacturer's recommendations. A new syringe of epoxy was used each time. Calibration was done only once at the start of each day using the sample size calculated for a 1% tolerance and 99% confidence. After calibration, a short run of 15 measurements was taken once per hour for four consecutive hours. Tests were repeated on five different days. Only one operator was involved throughout the trials. Pump results are shown in **Tables 3** and **4**. A typical run is shown in **Figure 8.**

Using appropriate sample sizes for the calibration process, targeting the pump output was successful to within a 1% tolerance at a target weight of 10.0 mg or ± 0.1 mg. In fact, the biases of long-term process averages were below 0.5%. This maximizes process performance as measured by Cpk. Long-term process performance results for the auger and piston pump were virtually identical (**Figure 9**).

Even though the long-term performance of the two pump types is identical, differences are observed in the short term. For the auger pump, group-to-group variation of the mean is larger than with the piston pump, but the average short-term variation is significant. While group-to-group variation for the piston pump is smaller than for the auger pump, short-term repeatability is larger, albeit more consistent.

References

1. Davis R. Bothe, *Measuring Process Capability*, McGraw Hill, 1997, pp. 1-347.
2. William J. Diamond, *Practical Experiment Designs*, Van Nostrand Reinhold, 1989, pp. 19-47.

Thomas Karlinski *is an R&D application engineer at Speedline Technologies (speedlinetech.com). He can be reached at tkarlinski@speedlinetech.com.*

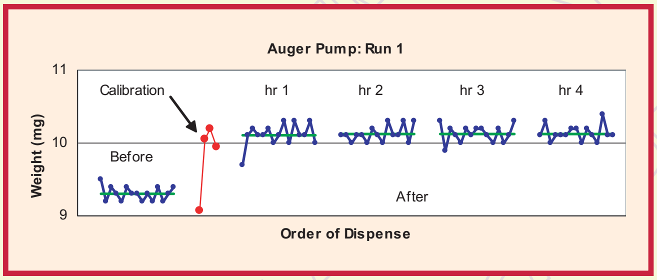

FIGURE 8: Test results of typical run, in this case using an augur pump.

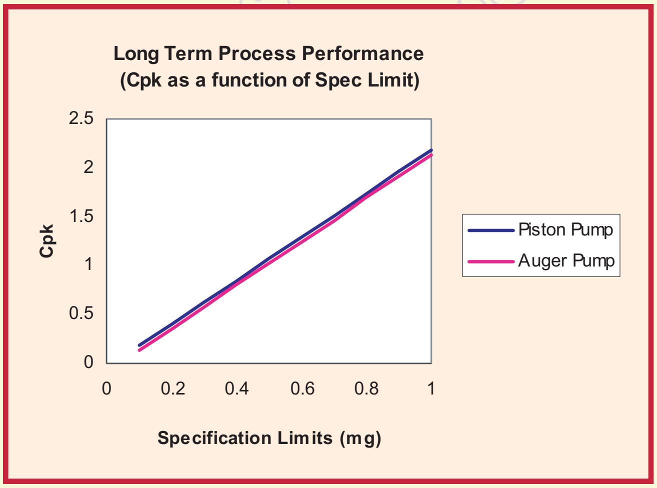

FIGURE 9: Long-term process performance (Cpk as a function of spec limit).