

Conformal Coating Process Controls: The Manufacturing Engineer's Aid

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Abstract

Methods for applying conformal coating to Printed Circuit Boards (PCB) evolved from crude dip and spray processes to selective coating. Selective coating provides benefits to the contract manufacturer as well as the OEM manufacturer. The addition of system controls, proven components, and application specific software further improves the process. This paper describes the components of selective conformal coating systems and how they aid the manufacturing engineer.

Background

Electronics manufacturing facilities come in many shapes and sizes. Even though each plant has specific needs and concerns, their common goal is to produce a quality product at the least cost. Engineers and technicians responsible for the conformal coating process represent the widely varying needs of contract manufacturers and Original Equipment Manufacturers (OEMs).

The Contract Manufacturer

Contract manufacturers typically have a high product mix. The production volume of each product can vary from low to high depending on customer orders and contracts. Because product lifecycles are decreasing, the manufacturer must be flexible and capable of responding quickly to customer's demands. Therefore, the engineer needs processes and equipment that are versatile and have short set-up times.

For some applications, a simple manual dip or brush conformal coating system may be adequate. Many low volume boards with only a few "keep-out" areas (i.e., coating is undesirable) like connectors can be coated quickly and easily with a dip, spray, or brush. An automated system is difficult to justify for such applications. However, if excessive masking or additional operations are required, a selective coating system may be justified by reducing downtime and labor while at the same time increasing repeatability. Equipment manufacturers have cost justification spreadsheets for determining whether a selective coating system is right for a process. In situations where the process engineer has many different boards to coat, an automated selective coating system allows him or her to easily switch products by just changing the coating program stored in the system's memory. The selective coating system can be justified for this reason alone.

The OEM Manufacturer

A typical OEM has a lower product mix and higher volume than a contract manufacturer. Since the OEM makes products for their own use, it is most economical to manufacture in their own facility. Due to the high capital investment required for an automated PCB assembly line, they typically run uninterrupted for long stretches of time. The challenge for the manufacturing engineer is to limit downtime and maintain repeatability of the coating. Therefore, the engineer selects equipment that requires little maintenance and has automatic control features that keep the process going with little operator intervention.

And The Rest...

Categorizing all manufacturers into contract or OEM is merely a convenience. Many manufacturers fit somewhere in-between. As a manufacturing or process engineer evaluates equipment, a list of requirements and objectives needs to be compiled. Items such as system safety, flexibility, ease of use, etc., need to be

considered when selecting a process and equipment. Table 1 lists some general system selection guidelines and Table 2 lists criteria to consider when evaluating a conformal coating system and its components.

Table 1. General Conformal Coating System Selection

		Production Volume	
		Low	High
Board Variety	Low	Manual	Automated Selective Coating
	High	Manual or Automated Selective Coating	Automated Selective Coating

Since the decision to choose a dip or spray system is simple compared to an automated system, our focus will be directed to automated selective conformal coating (for more information on alternatives see the list of references¹). Knowledge of the components and features of selective coating systems is critical in determining the best system for a particular manufacturing environment. After the needs of the operation are defined, the manufacturing or process engineer can select the desired features and components for the selective conformal coating system that best suit their needs.

Table 2. System and Component Evaluation Criteria

Feature	Criteria
Safety	Does it meet NFPA and CE safety standards?
Ease of Use	How user friendly is it?
Flexibility	How easily can the program or dispensing be switched?
Robustness	How often do parts need to be cleaned or replaced?
Controls	What controls are available and what is the quality or process improvement?
Software	Is the software designed for conformal coating?

Selective Conformal Coating System Components

Systems

When evaluating a selective conformal coating system (Figure 1), there are several system-level issues to consider: the degree of integration, flexibility, and safety. A highly integrated solution, designed with application-specific knowledge, is preferable to an ad hoc one. A system composed of motion devices, dispensers, and software all designed for the required task provides a more efficient, robust platform for conformal coating when compared to adapting general-purpose equipment.

Figure 1: Typical In-Line Selective Conformal Coating System

System flexibility is also important. The flexibility of a conformal coating system is a function of the types of coating materials it can handle, the sizes of boards it can coat, and how easily it can change between them. Flexibility is one of the primary concerns of a contract manufacturer, since they typically need to coat a wide variety of boards, possibly using several different materials. While integrated solutions and system flexibility are important, machine safety is the most important.

Safety is a serious and important aspect of the coating process. The use of solvent-based materials requires that the proper safety procedures be followed in order to prevent hazardous conditions. The fact that the selective coating process involves the use of a robot and conveyors enforces the need for approved guards and interlocks. Many production facilities require systems designed to US and European safety standards.

System ventilation must be designed to National Fire Protection Association (NFPA) 496² to be considered safe. The use of exhaust is a must with solvent-based material and with certain 100% solids materials. Exhaust used with non-flammable material is also important in order to eliminate offensive odors from the plant environment. The proper amount of airflow, in combination with the correct flow path, eliminates the possibility of hazardous fume build up. Volatiles can also be managed by reducing the amount of atomization in the dispense process. A non-atomized dispense is much less prone to combustion than an atomized spray.

A conformal coating system must also be designed for abnormal situations such as a solvent spill or a fluid system leak. Even if boards are not being coated with a solvent-based material, the equipment must be able to accommodate potentially flammable solvents used for cleaning.

All systems installed in Europe, and some in the US, require CE approval. CE approval governs construction and EMI/RF emissions for equipment. Construction requirements ensure the equipment has the proper safety features, such as interlocks, to insure operator safety and that proper materials and techniques are used in the system's construction. Electromagnetic Interference (EMI) emissions are generated by all electrical equipment and can cause many problems in a production line if excessive. CE approval ensures the system is designed and tested to maintain an acceptable level of emissions and that the equipment is not effected by emissions from other equipment.

Dispensers

Conformal coating dispensers can be classified into atomized or non-atomized deposition. Air-spray technology is an example of an atomization process. During atomization, breaking a material into fine particles, some droplets will drift. Most particles in the center of the pattern land in the desired area, but a certain percentage of particles land outside. The result is a non-uniform or ragged edge, which may not be acceptable. If a sharp edge is needed, a secondary pass with a bead dispense might be required. Some atomized patterns are better than others. If the air is mixed with the fluid internally in the dispenser (Figure 2), the material wicks into the cavity, requiring frequent cleaning. Dispensers with externally mixed air require little, if any, cleaning and produce a controlled atomization pattern.

Figure 2: Nozzle with Internally Mixed Air

Non-Atomizing dispensers can be in the form of a needle dispenser or film coater. A needle dispenser applies the coating in a narrow, thick band and is useful for small areas. A needle will tend to drip though, since the shut-off point is far from the tip. Dripping will cause problems if the coating lands on a connector or other undesirable location. Film coating is achieved by dispensing pressurized material through a crosscut³. This technique results in a leaf-shaped pattern of material (Figure 3). Film coating is most effective when using materials with a viscosity less than 150 cPs, as the minimum film build increases with material viscosity. Film thickness of .025 - .20 mm (.001 - .008 in.) is easily attainable with a repeatable, sharp edge definition.

Figure 3: Non-Atomized Film Coater

In many respects, the dispenser is the most critical component of the selective coating process. Since putting a quality coating on the board is the ultimate objective, special care should be taken when selecting

a dispenser. Repeatability, flexibility and maintainability are key criteria to consider when selecting a dispenser.

A process engineer looks for a repeatable dispenser to ensure quality. To ensure a repeatable dispensed pattern, the dispenser should be designed with the fluid shut-off close to the tip, which is called a zero-cavity dispenser or nozzle. This prevents dripping common to needle dispensing. Boards that have varying topography, or operations that have a variety of boards, require a flexible dispenser. Some dispensers such as a tri-mode swirl⁴ applicator³ allows maximum flexibility when processing boards that require different patterns. A bead mode performs the function of a needle without dripping (Figure 4a). As an external swirling pattern of air is introduced around the bead via software control, two separate dispense modes are possible: Monofilament and Swirl Spray modes. In Monofilament mode, the assist (shaping) air spins a single strand of material as it exits the nozzle. As the material stream spins away from the nozzle, it stretches into a conical-shaped looping pattern (Figure 4b). Monofilament mode provides excellent uniformity of build and edge definition with achievable film builds from .08 - .25 mm (.003-.01 in.). Swirl Spray occurs when the assist air pressure and velocity are increased, causing the material to atomize into a swirling, conical pattern (Figure 4c). The swirling pattern allows a controlled atomized dispense while maintaining good edge definition, overspray control, and uniformity of build. The three modes of operation are controlled by software and allow greater versatility when dispensing conformal coating onto a PCB.

Figure 4: Three Modes of a Tri-Mode Swirl Dispenser⁴: a. Bead Mode b. Monofilament Mode c. Swirl Mode

All dispensers need to be maintained, but when the dispenser needs cleaning or manual adjustment during a production run, production stops and the process engineer can become frustrated. Zero-cavity and externally mixed air dispensers reduce much of this untimely maintenance. A further improvement is automated cleaning components integrated into the coating system. A robust system parks the dispenser nozzle tip in a solvent cup to keep the coating from curing while waiting for a board to coat. Prior to coating a board, the dispenser moves to a brush box and moves its tip over the brushes to automatically clean the nozzle. This works well for robust dispensers that can handle the vigorous cleaning and reduces the need for manual maintenance by the operator. Needle dispensers are typically too weak for this and require delicate manual cleaning.

Software

Application-specific software designed for conformal coating provides many benefits when compared to general-purpose software packages. General-purpose systems often involve programming dispensing sequences in the equivalent of a CNC machine's M and G codes, and needlessly complicate the production engineer's job. There are at least two other problems with these general-purpose packages: low-level programming and mixing product-specific data with machine-specific data. Low-level programming requires a production engineer to learn the complicated intricacies of the system's controller, when they should be concentrating on coating their boards consistently and efficiently. The mixing of product-specific data with machine-specific data leads to process dependencies on both, requiring the dispensing sequence to be modified if either changes.

A distinct advantage of application-specific software for selective conformal coating is that it allows the engineer to program in terms of where the coating should be dispensed rather than the dispenser's trajectory. Easy-to-use, high-level, dispensing-specific instructions insulate the programmer from the complexities of the underlying hardware and machine language, reducing both training and programming time. For instance, to apply coating to a large, rectangular region, an AREA COAT instruction might be used. This instruction has a number of properties to specify how it executes. These properties include the coordinates of two diagonally opposite corners of the area to be coated. When executed, this instruction

causes the dispenser to apply a number of stripes of coating to fill in the rectangle. The software takes care of the details of turning the dispenser on and off at the appropriate times as it moves back and forth across the region. In contrast, to perform the same operation with non-application-specific software, dozens of separate instructions might be required to perform the required motions as well as enable and disable the dispenser at the appropriate times.

An Integrated Development Environment (IDE) designed for dispensing applications supports rapid programming and testing (Figure 5). An IDE consists of a system for editing and debugging. All programming, editing, and testing is done with the same software and interface. The editing system allows the instructions and routines comprising the dispensing sequence to be viewed and edited. The debugging system permits the dispensing sequence to be executed in its entirety or instruction-by-instruction. Optional breakpoints can be set on instructions causing the sequence to pause during execution, allowing the programmer to examine the state of the system before continuing execution. Additionally, any subroutine of the dispensing sequence can be executed independently, which allows the overall sequence to be written and debugged in a modular fashion. In comparison, non-integrated applications require the dispensing programs be edited in an external text editor, where writing a program consists of switching between the editing application and the dispensing application. This results in lengthier development cycles. Process monitoring during production is also recommended.

Figure 5: Conformal Coating IDE

Process monitoring provides a method for supervising the production of a coating system. Trends in a process can be identified through monitoring and data logging, allowing preventive measures to be taken before throughput or quality is compromised. Detailed software event logging provides a convenient method for data collection. Such a system should log commonplace events (e.g., "Board Arrived from Upstream Machine," "Coating Sequence Starting," "Board Exiting to Downstream Machine") as well as warnings (e.g., "Coating Fluid Reservoir is Getting Low") and errors (e.g., "Failure to Load Board from Upstream Machine after Repeated Attempts"). Log entries need to be date and time stamped. The time stamps allow statistics, such as average cycle time, to be calculated and help to correlate system events to external events. User-defined logging events provide a convenient method for production personnel to add customized messages (e.g., "Coating Part Number XYZ-123") that can be useful for their own monitoring and analysis. It is useful to both display these events for the operator (Figure 6) and create a permanent record on the system's hard disk.

Figure 6: Software Event Logging

Controlling process variables is crucial to maintaining the quality of a system's output. Configuration variables in a software system make this doubly difficult since they are easy to modify (both deliberately and inadvertently) and often have poor operator visibility. Therefore, it is important that the software is capable of controlling different levels of access to the code. Typical operators need limited software access, whereas production engineers must be able to modify dispensing sequences and system parameters. Operating on a stable, secure platform⁶ provides some measure of protection since the system's built-in access control features can be utilized. Access control features integrated into application software add another layer of protection.

Process Controls

As selective conformal coating systems evolved, process controls have been improved. Process controls, in conjunction with software development, aid the manufacturing engineer and operator in reducing system maintenance and improving the coating quality.

Since the quality of a coated board depends on a repeatable coating dispense, controlling the output of the dispenser is crucial. Typical dispensers produce a fan, cone, or bead pattern. With a given nozzle, the width of the pattern is governed by the fluid pressure and viscosity. Changes in viscosity, caused by temperature variations, can affect material flow and fan width and vary the coating deposition. Frequently, the operator will adjust the dispenser parameters in attempt to control the process. An automatic fan width control device will take the operator out of the crude, manual adjustment process. The fan width control (Figure 7) automatically measures the fan width with a light beam and adjusts the pressure to maintain the same fan width. Monitoring the dispensed pattern width alerts the operator of potential problems and ensures that the same coating pattern is dispensed every time, thereby improving product quality.

Figure 7: Fan Width Control Hardware

Monitoring the fluid level manually can be tedious for the operator and there is a risk of introducing error into the process. If the fluid level is not monitored, the fluid could run out and many uncoated boards could pass through the line before the problem was noticed. Most fluid reservoirs are opaque, so operators cannot easily tell when they are empty. Continually opening the reservoir to check the fluid level is not a good solution because moisture and contamination can enter the fluid system. Adding fluid level monitors and low fluid alarms to the system alert the operator to refill fluid reservoirs before they are empty.

Changing material from an empty to full reservoir takes time used for maintenance away from valuable production time. The automated material changeover system allows the fluid system to automatically switch quickly from an empty reservoir to a full reservoir. A typical system has two reservoirs and monitors the weight of each. Assume the conformal coating fluid is currently being pumped from Reservoir A. As the level dips below the low limit, a warning light on the light tower is enabled, indicating the reservoir is nearly empty. As the weight of Reservoir A drops below a low limit, the system releases the pressure in Reservoir A, switches the flow path to Reservoir B, and pressurizes Reservoir B. The fluid in Reservoir A can then be replaced at any time while pumping from Reservoir B. When Reservoir B empties, this process reverses automatically. Some systems use conformal coating stored and pumped from bags or bladders that are placed in reservoirs. The closed bags prevent fluid contamination and further reduce the changeover time. The material changeover system eliminates downtime when the reservoir needs to be refilled and reduces the chance for boards to pass through the workcell uncoated.

Automated product handling reduces the chance for operator error and improves throughput. Every time an operator handles a PCB there is a risk of contamination, dropping the board, or disturbing the uncured coating. Also, static sensitive boards are at risk from Electrostatic Discharge (ESD). Conveyors move boards into and out of a workcell without operator intervention. Many PCBs require coating on both sides, so the board must be flipped. Automated board inverters and flippers (Figure 6) remove the risk associated with operator board handling. With automated handling, boards can pass through the conformal coating process safely and reliably.

Figure 8: In-Line Board Inverter

Summary

The needs of contract manufacturers and OEMs can be met with selective conformal coating systems. An integrated system that provides coating flexibility and safety will serve the manufacturing engineer better than a makeshift one. A careful choice of dispenser technology, whether atomized or non-atomized, will maximize flexibility and reduce maintenance. Application-specific software, designed for selective conformal coating, provides a powerful set of tools for writing dispensing programs and monitoring and controlling production. Finally, the use of process controls reduces system maintenance, downtime and improves coating quality and repeatability.

¹ Byers, J. and C. Havlik "Considerations in Dispensing Conformal Coatings," *NEPCON West '99 Conference Proceedings*, February 1999.

² National Fire Protection Association, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*. 1998.

³ e.g., Nordson Corporation's Cross-Cut® Dispenser.

⁴ e.g., Nordson Corporation's Swirl Coat™ Dispenser.

⁵ Fox, K., C. Havlik, and D. Selestak, "Contemporary Conformal Coating Application Techniques 'Swirl It On,'" *NEPCON West '97 Conference Proceedings*, February 1997.

⁶ e.g., Microsoft Windows NT®.