ADVANCEMENTS IN CONFORMAL COATING PROCESS CONTROLS

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Overview

Methods for applying conformal coating to Printed Circuit Boards (PCBs) have evolved from the crude dip and spray processes to selective coating. This paper will review the history of process development and how the use of process controls evolved. Quality improvement, ease of use, and system safety are all other benefits attained with process controls that will be discussed in detail.

Background

Conformal coatings protect electronic products from solvents, moisture, dust or other contaminants that may damage them. Coating also prevents dendrite growth, or oxides growing on the PCB. Dendrite growth can create short circuits and result in product failure. A variety of techniques for applying conformal coatings to products are used in the electronic industry. Like most manufacturing processes, conformal coating application methods have evolved from manual to automated systems.

In the beginning...

One of the oldest and best-known methods of coating is the dip process. In the manual dip operation, operators immerse the PCB in a tank of coating. Components on the PCB that cannot be exposed to coating must first be masked (Figure 1). Tape or boot masking (boot masking is typically used for spray applications and are not “water-tight” enough for submersion) is manually applied prior to coating. The masking is then removed after the board is cured. Masking is labor intensive and involves consumables, making the process inherently wasteful. Some dip systems automatically move the board in and out of the tank, allowing for better repeatability. Although dip systems are simple and involve a low capital investment, the variation in coating thickness, contamination issues, viscosity variations, manual masking, cleanliness and operator comfort and exposure make this a crude process with little control.

Brushing the material on the PCB is another method used to conformally coat a PCB. This is typically a manual process in which an operator dips a brush into a container of coating material, and then brushes the material onto the PCB. There is little investment in equipment or tooling and the process is simple, but crude. Brushing introduces the same problems.
associated with the dip process. Although brushing may be adequate for low volume prototype runs, this process is not viable for mass production.

Manually air-spraying the board is another common method for applying a thin film of conformal coating material to a PCB (Figure 2). Since air spraying produces a large amount of over-spray, hand masking is required beforehand. After the masking is complete, the boards are laid out or hung in a spray booth. An operator sprays the PCB’s with a hand held spray gun similar to those used to spray paint. Once the boards are cured, the masking material is removed. The operator is continuously exposed to the coating during and after the process, which can create safety and health issues. The coating thickness and consistency is operator-dependent and not highly repeatable.

The introduction of needle dispensing, which can be done manually or robotically, was a marked improvement for conformal coating. The coating material is forced through a needle and is dispensed as a bead. Beads of material are placed in different locations on the board and through capillary action produce the desired coverage. The manual needle dispensing equipment cost is low, but is operator-dependent and not highly repeatable. Automated needles dispense systems increase repeatability, but fast coverage and dispenser robustness are difficult to achieve. Table 1 summarizes the advantages and disadvantages of various systems.

Table 1: Relative Comparison Conformal Coating Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Masking</th>
<th>Contamination Risk</th>
<th>Coating Repeatability</th>
<th>Viscosity Variation</th>
<th>Cleanliness</th>
<th>Cost</th>
<th>Transfer Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dip</td>
<td>Yes</td>
<td>High</td>
<td>Poor</td>
<td>High</td>
<td>Poor</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Brush</td>
<td>Little</td>
<td>High</td>
<td>Poor</td>
<td>High</td>
<td>Poor</td>
<td>Lowest</td>
<td>Medium</td>
</tr>
<tr>
<td>Air Spray</td>
<td>Yes</td>
<td>Medium</td>
<td>Fair</td>
<td>Low</td>
<td>Poor</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Needle (manual)</td>
<td>Little</td>
<td>None</td>
<td>Low</td>
<td>Fair</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Selective Coating</td>
<td>Little</td>
<td>Low</td>
<td>Good</td>
<td>Low</td>
<td>Good</td>
<td>Higher</td>
<td>High</td>
</tr>
</tbody>
</table>

**At last, a New Horizon…**

Major improvements in conformal coating can be realized through the use of automated systems that selectively apply coating. A dispenser mounted to a robot is programmed to move and dispense material in designated locations on the PCB. The system can be manually
loaded or equipped with conveyors for inline board processing. The coating material, dispenser type, and robot speed determine the coverage and film build. Selective conformal coating machines provide consistent application of material, higher throughput, material savings, closed fluid systems and, given the proper dispenser and PCB layout, do not require custom tooling or board masking. The main disadvantage is the cost of a selective conformal coating machine compared to other methods.

The conformal coating process has benefited from increased automation in recent years. Conveyors and board handling equipment have been added to reduce operator errors and reduce (or eliminate) board damage before and after coating. Improved fluid delivery methods increase both product quality and system flexibility. Graphical, user-friendly software developed specifically for selective conformal coating simplifies process development and operator interface. Quality improvement, ease of use, and operator safety should be carefully considered when procuring a conformal coating system.

Quality Improvement

The equipment used in the conformal coating process has evolved to provide a more repeatable and higher quality process. As previously discussed, the major improvement, to date, has been going from dip, brush, and spray processes to automated selective coating. The focus of the following discussion will be limited to the selective coating process. The cost of low quality can be measured in board rework or scrap, production downtime, and excess material usage. Within the selective coating process the dispensers, controls, and software have been developed to further improve the coating quality, reducing quality associated production costs.

Dispensers

Conformally coated PCB quality begins with the dispensing process. Some factors to consider when evaluating and working with different dispensers are the deposition method, dripping issues, and adjustments needed during production. Selecting a dispenser that provides the best deposition for a particular product is crucial to attaining the desired coating quality.

The conformal coating deposition, which can be classified as either an atomized or non-atomized process, has an impact on the outcome of product quality. Air-spray technology is an example of an atomization process and has inherent over-spray. 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.
One measure of the dispense process is transfer efficiency. Transfer efficiency is the percentage of material that is deposited in the target area. Air spray technology has a typical transfer efficiency of 70 – 80%. This means that 20 – 30 % of the material falls outside of the target area and is wasted. If the material does not end up on the PCB at all (areas close to the edge of the board), the excess over-spray lands on the dispensing equipment, which must be cleaned periodically.

Film coating is an example of a non-atomized process and is achieved by dispensing pressurized material through a crosscut nozzle. 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.) are easily attainable with a repeatable, sharp edge definition.

Coating PCBs can be a messy endeavor. When the dispenser is shut off, there should be no dripping from the tip. Since dripping is an uncontrolled event, the drip can easily fall into a keep-out area on the PCB (like a connector) or on the system conveyor, leading to poor quality and board rejects. Typical needle dispensers have a tendency to drip because the shut-off is far from the tip. However, there are dispensers designed with the shut-off close to the tip, called zero-cavity dispensers or nozzles. Selecting a dispenser with positive shut-off close to the dispensing tip is crucial for reliable operation.

Dispensers that require frequent adjustments during production lead to variations in coating. Dispensers that mix air with the coating fluid internally may need frequent adjustment or cleaning due to material wicking into the air cavity and subsequently curing (Figure 4). Robust dispensers do not have air mixing or mix the fluid with air outside the dispenser nozzle. These dispensers require little, if any, adjustment during production while providing a consistent coating from board to board.

Controls

Automatic control and monitoring of the fluid system greatly improve process quality by reducing manual adjustments. 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. If the fan width varies from board to board, so will the coating deposition. A fan width control device (Figure 5) 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, improving product quality.

Monitoring the fluid level is important for maintaining both production quality and throughput. If the fluid level is not automatically 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 permit the operator to refill fluid reservoirs before they are empty.

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.

**Software**

One of the keys to maintaining high quality is process monitoring. Trends in a process can be identified through monitoring and data logging, allowing preventative measures to be taken before throughput or quality is compromised. Detailed software event logging of an automated conformal coating system 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”). It is useful to both display these events for the operator (Figure 7) and create a permanent record on the system’s hard disk. A mechanism for rotating log files is needed to ensure disk space is not exceeded.

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. Additionally, the events can be filtered before going into the log. For instance, a system may be configured to display only warning and error events to the operator while all events get logged to the disk.

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 software for automated coating systems limit access to important variables to qualified personnel. Typical operators need limited software access while production engineers must be able to modify dispensing sequences and system parameters. Operating on a stable, secure platform, such as Microsoft Windows NT®, provides some measure of protection. Access control features integrated into application software add another layer of protection. Further software features, such as a mechanism to match product part numbers to coating sequences, help prevent the wrong coating sequence from being used to coat a board.

**Ease of Use**

**Dispenser Flexibility**

Dispenser flexibility is important when trying to select a coating process. Multiple dispensers on a single robot can be cumbersome as well as difficult to maintain. Single dispensers that can operate in multiple modes are more versatile and easier to maintain. In addition, when a single dispenser can produce multiple patterns, a second dispenser mounted on the robot can be used to either increase throughput or dispense a different material for another application. In this case, the dispensing modes are controlled electromechanically, typically by software, allowing the modes to be changed automatically.

A Tri-Mode applicator allows maximum flexibility when processing boards that require different coating patterns on a single board. The Tri-Mode applicator supports three modes: Bead, Monofilament, and Swirl Spray. Bead mode is a single stream of material dispensed through a nozzle (Figure 8). This mode provides excellent edge definition and a thick film build. Bead mode is typically used to apply extra material along a component or connector edge, or to build a dam around an area of coating. To ensure accuracy, the dispenser should be of the zero-cavity type to minimize the material volume past the shut-off point. This reduces the drooling and stringing that can occur with a needle tip.

By adding external assist air 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 9). 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. 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 for great versatility in dispensing conformal coating onto a PCB.

A non-atomized film coater’s fan pattern (Figure 3) can be varied electromechanically providing a wide range of dispensing patterns. When coating a board, a small width may be needed in a tight area, whereas a wider width may be needed to quickly coat a large area. Since the fan width is related to the fluid pressure, a software-controlled pressure regulator quickly adjusts the fluid pressure to set the desired width. Multiple fan widths can be set and calibrated with the fan width control system and stored in the coating program. By automatically controlling these multiple widths, an accurate, repeatable edge may be produced while increasing throughput and system flexibility.

Software

Due to the complexity of an automated conformal coating process, application-specific software is required. General-purpose software (e.g., motion controller languages), pressed into service for dispensing invariably puts the burden of complexity on the programmer rather than on the software where it belongs. Programming dispensing sequences in the equivalent of a CNC machine’s M and G codes needlessly complicates the production engineer’s job. This approach mixes product specific data with system specific data, requiring changes to the dispensing sequence if either the PCB or the system parameters change. A primary advantage of application-specific software for selective conformal coating is that it allows the engineer to program where the coating should be dispensed, not 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 might require dozens of separate instructions to coordinate the motion of the dispenser with enabling and disabling of outputs to control the nozzle.

Added benefits of application specific software are help files and documentation. Using a standard platform and GUI, such as that provided by Microsoft Windows®, can also reduce training time since many operators and engineers are increasingly familiar with its interface.

An Integrated Development Environment (IDE) designed for dispensing applications supports rapid programming and testing. An IDE typically contains an editing and debugging system (Figure 10). The important point is that the system is truly integrated: all programming, editing, and testing is done with the same software. The editing system allows the instructions and routines comprising the dispensing sequence to be viewed and edited. In comparison, some non-application-specific software packages require that programs be edited using a text editor, external to the application. 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. These features of a coating specific software application help to accelerate program creation and testing.

**Maintenance Reduction**

Reducing the amount of maintenance required during production permits the process to run smoother with fewer interruptions. Accessories, such as automated material changeover and automated cleaning components in a workcell, accomplish just that. Using dispensers with higher transfer efficiencies also reduces maintenance since limiting over-spray reduces the amount of clean-up time required.

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.

Since conformal coating can cure or clog the tip of a dispenser when it is not in the dispensing mode, automated cleaning components reduce system downtime caused by removing unwanted material on the dispenser. A robust system will park the dispenser nozzle tip in a solvent cup to keep the coating from curing. Prior to coating a board, the dispenser will...
move to a brush box and move its tip over the brushes to automatically clean the nozzle. This works well for robust dispensers that can handle the vigorous cleaning. Needle dispensers are typically too weak for this and require delicate manual cleaning. Another advantage is that automated cleaning reduces operator intervention.

Typical routine maintenance includes keeping the machine clean and lubricated. If the conveyor rails continuously collect over-spray from the coating process, the conveying process may not be consistent and could possibly fail. The use of a dispensing technology that limits or eliminates over-spray can significantly reduce maintenance time.

Safety Considerations

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 guarding and interlocks. Many production facilities require systems designed to US and European safety standards.

Ventilation

System ventilation must be designed to NFPA 496 to be considered safe. NFPA 496 is a standard written by the National Fire Protection Association for ventilating electrical enclosures. 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 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.

The equipment and process must also allow for abnormal cases such as a fluid system leak or a solvent spill. Correctly engineered systems have the proper spill containment. 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.

CE Approval

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.

Summary

Moving from crude spray and dip processes to selective conformal coating improves throughput and quality. The use of sophisticated dispenser technology provides a better, more repeatable coating as well as additional process flexibility. Advancements in monitoring fluid levels as well as controlling dispenser patterns create more robust, flexible systems. Software enhancements for data logging and system monitoring provide tools for monitoring and controlling a system. Flexible dispensers and user-friendly, application-specific software meet the needs of a wide variety of applications. Improved safety, including ventilation and adherence to broad safety specifications, create a safer and more comfortable environment for operators.

Conformal coating has seen marked improvement in quality and efficiency as the associated process technology has evolved. With the addition of better process control, automated conformal coating systems are poised for revolutionary improvements in quality, ease of use, and safety.

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