CONSIDERATIONS IN DISPENSING CONFORMAL COATINGS

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Introduction

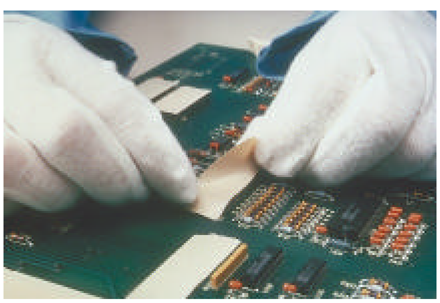
Conformal coating is a material that is applied to electronic products or assemblies to protect them from solvents, moisture, dust or other contaminants that may cause harm. Coating also prevents dendrite growth, which may result in product failure. This paper will discuss the variables that affect the application of conformal coatings, and review in detail those variables that impact the process of selective coating of printed circuit boards.

Methods of Applying Conformal Coating

As with most processes in the electronics industry, there are several ways to apply conformal coatings to the product. Some of the methods are typically performed manually while others are automated.

Dip Coating

One of the oldest and best-known methods of coating is the dip process. The dip process can be done manually or automatically. In the manual mode, operators immerse the PCB in a tank of coating. The PCB is either immersed totally or to a predetermined level on the board. Some manual dip systems will automatically move the board down into the tank and remove the board from the tank. This allows for more control.

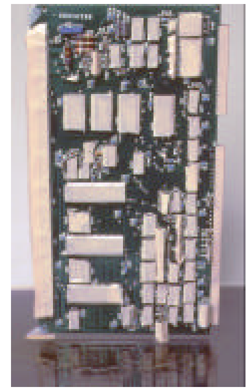


Manual Masking

Automatic dip systems consist of a tank of coating and a conveyor to move the PCB's. The PCB's are put on hangers, conveyed to the tank, moved through the coating and then removed. The speed of the conveyor determines the amount of material applied. With either manual or automatic systems, components that can not be exposed to the coating but are below the dip line must be masked.

Dip System (typical)

The advantages of dip systems are low capital investment, simplicity and high throughput. Disadvantages include lack of consistency of material thickness, contamination issues, viscosity variations, manual masking, cleanliness and operator comfort.



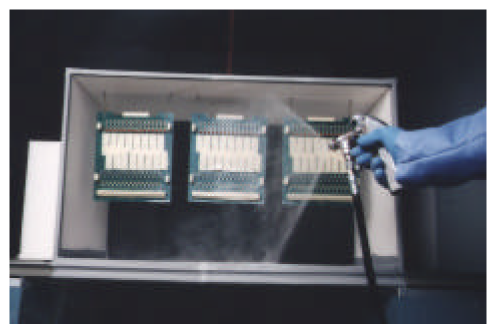
Board after dipping (note drips at bottom)

Brush Application

Brushing the material on the PCB is another option. This is a manual process where an operator dips a brush into a container of coating material and brushes the material onto the PCB. There is no equipment investment, no tooling or masking required and the process is simple. Disadvantages include operator exposure to material, inconsistencies in coverage, material contamination and viscosity variances. Although brushing may be adequate for low volume prototype runs, this process is not viable for mass production.

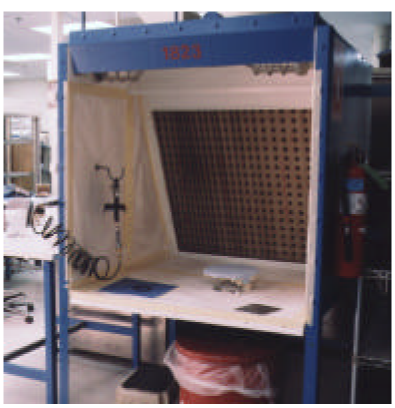
Atomized Air Spray

Air spraying (painting) the board manually is another common method used to conformally coat PCB's. Since air spraying involves a lot of overspray, components on the PCB that can not be exposed to coating must be masked. Masking is done manually with either tape or boots. After the masking is done, the boards are laid out or hung to allow for exposure to the spray. An operator will then spray the PCB's with a hand held spray gun similar to those used to spray paint. The boards are allowed to cure and then the masking material is removed.



Boards being air-sprayed (note over-spray)

The advantages of air spray are similar to brush and dip; low capital costs, simplicity and limited tooling. The disadvantages are safety, operator comfort, masking, consistency and cleanliness.



Manual Spray Booth

Needle Dispensing

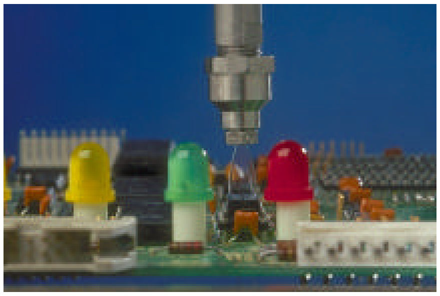
A needle dispense can be done by hand or on a robot. A simple spool valve can be used to turn material flow on and off. The material is forced through a needle and is dispensed as a bead. The beads are placed in different locations on the board allowing the material to flow to supply the appropriate coverage.

Advantages of a manual system include low equipment cost, simplicity, no tooling, a closed fluid system and no masking. Disadvantages of the manual system include inconsistencies in material placement, high film builds and low throughput. The automated system has the advantages of repeatable material deposition, closed fluid system, and no masking. Some of the disadvantages of the manual system remain; high film builds, low throughput (when compared to other automated systems) with the additional medium capital expenditure for a robotically controlled machine.

Automated Selective Coating System

Automated Selective Coating

Conformal coating can also be selectively applied. A dispenser is mounted to a robot. The robot is programmed to move and dispense material in designated locations on the PCB. The machines can be manually loaded or use conveyors for inline processing. The type of dispenser and speed of the robot determines the coverage and film build.



Cross-Cut Nozzle dispensing a Non-Atomized Fan Pattern

Advantages of selective conformal coating machines include; consistent application of material, high throughputs, no custom tooling, material savings, closed fluid system and no masking (with the proper dispenser). The main disadvantage is the cost of a selective conformal coating machine compared to other methods.

The choice of the appropriate process and method depends on the situation for each application. Although decisions are typically made on a ROI basis, operator safety and quality should be the driving factors.

Types of Conformal Coatings

Conformal coatings are typically classified by polymer type. There are five major categories (acrylic, polyurethane, epoxy, silicone and paralyene), with a few hybrids and special types (acrylated urethanes, acrylic-modified silicones, polyamides) rounding out the choices.

Acrylic Resins

Acrylic resins (AR) are typically solvent-based formulations, are easy to apply and repair, while providing good protection against moisture and abrasion. Their limitations include poor solvent resistivity, poor temperature resistance and fair mechanical strength.

Polyurethane Resins

Polyurethane resins (UR) offer different characteristics than acrylics; excellent humidity resistance, better mechanical strength, better abrasion resistance and better resistance to solvents. Urethanes are typically more difficult to remove (especially UV types) and may present application difficulties due to moisture sensitivity and pot life issues. Urethanes are offered in both single and plural component systems. Single part systems are easier to apply and have a longer pot life than plural component systems, but the cure time is extended, typically reaching as long as seven days. Plural component systems (resin, catalyst and possibly a solvent thinner) offer quicker cures due to the rapid cross-linking of the molecules after mixing, but this cure also presents challenges in dispensing, such as nozzle clogging and viscosity change management. If a solvent is present, it must be flashed off prior to curing. Failure to do so may result in solvent being entrapped in the conformal coating, which could cause shorts or remove coating in critical areas.

Epoxy Resins

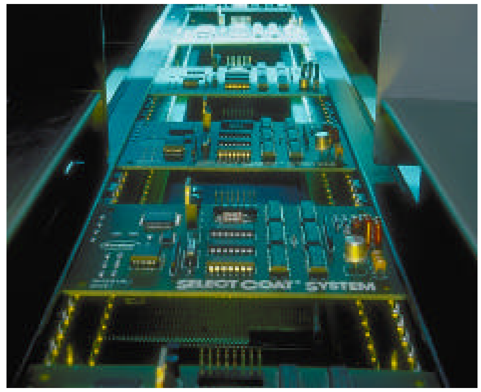
Probably the least commonly used coating material is epoxy resin (ER). Epoxies offer excellent mechanical strength and abrasion resistance, as well as good humidity resistance. However, epoxies offer poor temperature resistance, poor reparability and poor flexibility. Since most epoxies are plural component, they present the same dispensing challenges as plural component urethanes. An additional concern with epoxy is the risk of thermal expansion/contraction if flowed under components. Care should be taken to minimize the amount of material under components (especially plcc/bga/surface mount packages) to avoid potential problems. Care should also be taken when mixing the components, as most plural component materials are sensitive to being *off ratio*, leading to soft, uncured material or material that is too hard. The ideal mix system would be a programmable metering system to ensure proper mixing. If the material is heavily filled, a shot pump system should be used rather than a gear metering system. Many applications for ER in the electronics field involve potting or staking, rather than conformal coating.

Silicone Resins

Silicone resins (SR) provide excellent temperature resistance, as they typically have a very low thermal coefficient of expansion. Silicones also offer good resistance to moisture. Silicones are available in moisture cure (RTV), heat cure (with or without moisture secondary cure) or UV cure (moisture secondary cure). Some RTV cure materials present application difficulties due to their quick moisture cure, while some heat cures may become contaminated during board processing, preventing them from curing (platinum cure). Silicones also offer poor abrasion resistivity and poor mechanical strengths. Most SR are single component systems. A few two-component silicone materials are available.

Curing Methods

Conformal coatings cure via several methods: Heat, moisture, UV, chemical reaction or a combination of several methods.



Automated UV Curing Module

Moisture Curing

Moisture curing requires exposure to humidity at a specified level for a given duration. In humid environments (say, Houston in late July), external control is likely unnecessary. However, in many cold climates, the winter months present difficulties in maintaining facility humidity. In these cases, a batch humidity chamber or an inline FIFO humidity buffer might be employed to regulate the humidity level and exposure while the material vulcanizes and/or cross-links. The source of humidity is critical to prevent contamination. An evaporative humidifier or steam generator is preferred over an ultrasonic humidifier due to the particulate present with ultrasonic units.

Heat Cure

Heat for curing is typically a combination of infrared and convection. Heat is used in two different ways depending on the chemistry of the material. The first method evaporates solvent that is present in the coating material. The material that remains is the protective conformal coating. The material may be partially cured and will dry as it continues down the assembly line.

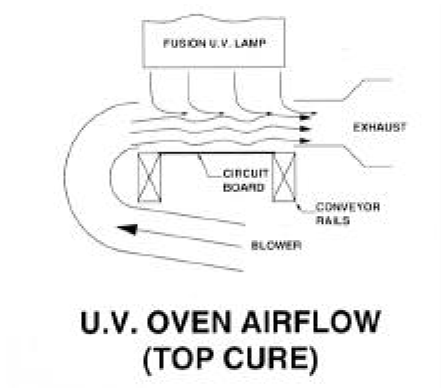
In-line Infra-Red Coating/Curing System

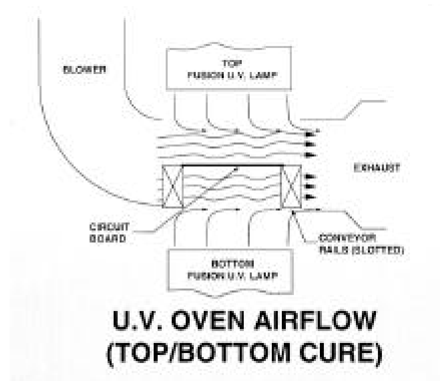
The second method uses the heat to trigger a chemical reaction. This method requires a specified duration of time at or above a certain temperature to react. If the material fails to reach the proper temperature, the cure reaction will not take place at all. Care must be used when evaporating solvents in an oven, as flammable gasses present an explosion hazard if not removed at the NFPA specified level.

Ultraviolet Cure

UV cure materials cure reactively in a short period of UV light exposure. UV cure is quick and eliminates the need for long ovens. However, it also presents several challenges: The most efficient UV lamp system available produces only 35% UV light. The balance of the energy is IR and visible light. The IR can create an extremely high rate of rise temperature curve, so extreme in some cases that components simply pop off the board. To address the heat situation, proper airflow management must be employed. By moving cool air across the surface of the conveyor, between the PCB and the lamp, temperature rise rates can be kept in the 3°C to 4°C range. Another UV cure challenge is presented by material that flows under components and is shadowed from the light. A secondary cure mechanism such as moisture or plural component will solve this problem, but the secondary cure must be fast acting to prevent dripping of material during downstream processing of the board.

In-line Ultra-Violet Coating/Curing System





<u>Reactive Curing</u>

Chemical reaction curing is typically seen in plural component systems (resin, catalyst, solvent). These systems are an excellent solution where fast cure is required. Plural component materials typically employ a secondary cure mechanism (such as UV light). Reactive cure is better as a secondary cure mechanism.

Variables in the Coating Process

<u>Process Description</u>

The conformal coating process is one of the last processes on the PCB assembly line. This is due to the fact that once a PCB is coated it is very difficult to repair. A typical production line would have surface mount, odd form placement,

wave solder, touch-up, circuit test, functional test, conformal coating, routing and assembly into final product.

The configuration of the selective conformal coating process itself will vary depending on the throughput requirements and application. The simplest form of the process would be a manually loaded and unloaded workcell. This would have an operator loading the product into the machine; initiating the coating sequence; the robot moving the dispenser in a programmed sequence to coat the boards; the operator removing the product; and placement of the coated product into an oven or rack for curing.

To automate the selective process, material handling equipment is added to the machine to minimize operator intervention. An upstream conveyor would send a product to the entry conveyor of the coating cell. The product would be conveyed to the coating station, registered and coated. The product would then exit and proceed through a curing module.

Inverter Module

To perform two-sided coating, some form of flipper or inverter is added to the process. For two-sided coating with higher throughput requirements a second coating cell may be added so that the configuration is coat, invert, coat and cure. Coating lines are application engineered on a regular basis to meet different process and coating needs.

HV UV System with Flipper Module

IR System with Inverter Module

Flipper Module

Coating Materials

The choice of material is an important consideration in a selective coating application. Once a material type has been determined, a material with a given viscosity range and flow properties that allow proper dispensing must be chosen. A material with a high viscosity will be less likely to flow when dispensed, but will also be less likely to self-level. A low-viscosity material will *flow out*, especially under components and into hard-to-reach areas. However, it may also wander into keep-out areas as well. Most material types are available in a wide range of viscosities. Material suppliers can modify materials to provide desired flow characteristics.

Pot life of the selected material is of great importance. If the material viscosity is changing, pattern and flow control become moving targets. Single-component materials generally provide a longer pot life, but may not provide the rapid cure required by some applications. Single-component materials may also be moisture or contamination sensitive, which may lead to a change in viscosity or a shorter pot life. Materials that are contamination or moisture sensitive can be purchased and supplied in a bladder to protect them from the local atmosphere. Plural component materials typically have good cure characteristics, but can present application problems due to short pot life or rework issues due to the toughness of the cured material.

Other rheology issues can present additional challenges. Shear thinning makes viscosity control difficult, while shear sensitivity makes the pumping method critical. High capillary tendencies make controlling the material after dispensing difficult, but may help the material flow into areas that can't be reached by the dispenser.

One important issue is often overlooked. Conformal coating equipment is only as flexible as the material allows it to be. Changing from an organic to a silicone material is acceptable if the proper procedures are followed. Flushing the fluid system and dispenser with the proper solvent and possibly with air or an inert gas will allow the silicone material to be dispensed correctly. However, changing from a silicone to an organic material is almost impossible. Silicone is very difficult to remove regardless of design or material used in the fabrication of the fluid system and dispenser. If the silicone is not completely flushed, the new material may de-wet (fish-eyes), partially cure and clog the dispenser, resulting in unacceptable material application and boards that must be reworked or scrapped.

Material viscosity changes with temperature. Most material suppliers supply a temperature vs. viscosity curve with the technical data sheet. When the temperature of the material changes, viscosity also changes and the amount of material dispensed will be incorrect. The amount of variance in the volume dispensed depends on the material sensitivity to temperature and the amount of fluid pressure used to dispense. If the material is sensitive to temperature variations, the material may be heated to a temperature slightly above ambient conditions to maintain the viscosity throughout the day. Low-fluid pressure dispense methods will have a greater change in volume dispensed leading to variances in film build throughout the day.

Board Layout and Design for Selective Coating

One of the most commonly asked questions received from design engineers is how to best design their new products for automated selective coating. The following items are suggestions for an ideal board for selective coating. In the real world, many may prove difficult, and other solutions such as a material dam, a cap or a mask may be considered.

SMEMA standards specify that the board should have 5 mm of edge clearance along the two handling edges. This will help keep the belt or chain conveyor clean. Tall components placed along these edges or connectors will present difficulties in achieving adequate coverage without coating the 5-mm keep-out.

Connectors should be placed along the edges if possible, with the pins facing out to avoid application of coating material to connector pins. Many connectors are sealed, but if open connectors are used (i.e. square pin in a round hole), care must be taken to ensure no wicking of material up the pin and through the plastic occurs. Some coatings have tremendous capillary action. Vertical connectors may require caution if the area between the board and connector requires coating, but no coating is allowed on the pins.

Holes through the board (for mounting, tooling or large vias) should be placed away from components, as material is apt to flow through the hole and drip on the machine base plate. The worst case is a component actually straddling the hole. When applying coating to the component, material will be dispensed through the hole, which will cause material build up within the coating area, requiring extra clean-up and maintenance. If holes are unavoidable, a low pressure spray is best used to keep the coverage under 2 mils to prevent dripping. Solvent-based materials present an especially difficult challenge when high dry builds are required. Either a dam and fill, or a multiple coat and cure solution might be considered.

Another challenge is achieving coverage under displays or large connectors with SMT or other small components under them. LCD displays allow coating between the leads if the spacing is greater than 0.025" by dispensing and flowing the coating through the leads. Air assist may be used to move the coating further under the components after the initial bead has been dispensed. Material selection is important for these applications, as UV light can not get to a shadowed component, and IR energy can not penetrate to warm the material quickly.

Environmental Conditions

As described above, there are several different types of cure mechanisms available with today's conformal coatings. There are also several different ways in which the material can be affected by changes in the plant environment. Proper handling of the fluid in the system can prevent a number of process problems. For example, sending UV-curable materials through the wrong (clear) tubing or pressurizing moisture-cure material with shop air could result in viscosity changes, partially cured material and unacceptable coating results.

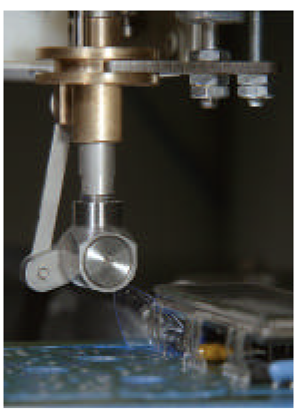
Dispensing

Conformal coating can be applied by many methods, from a single dispenser or multiple guns ganged on the robot. Conventional air-spray and needle dispensers can be used to apply coating to a PCB that require different depositions of material in separate areas. An innovative dispenser is available that applies coating using three modes from a single dispenser.

An air-spray valve can be used to apply most conformal coatings. It is a simple solution and these dispensers are readily available. The air-spray valve will fit certain applications well. For example, if edge definition is not critical and the film build requirement is 1 mil, an air-spray gun may work. However, the limitations of air-spray may preclude its use.

If a machine is properly ventilated according to NFPA standards, there will be air-flow through the coating area. If low pressure air is used to atomize the material and form the dispense pattern, the air flow from the ventilation will disturb the pattern and cause inconsistent coverage on the board.

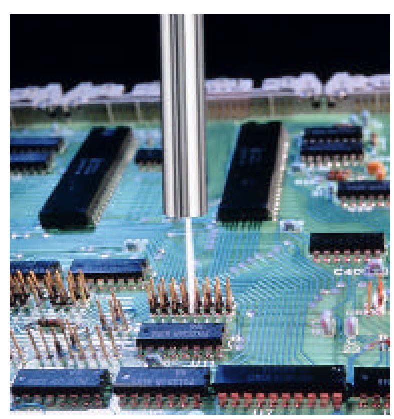
Typical air-spray technology has inherent overspray. The technology of breaking the material into fine particles leads to the inevitable fact that not all of the particles will land in the desired area. There will be a normal distribution of particles through the cross-section of the desired pattern with a certain percentage landing outside. The result is a non-discrete edge. Again, this may fit some applications and not others.



5-axis Film Coater

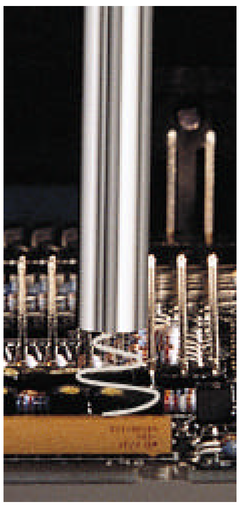
Film coating is achieved by dispensing pressurized material through a cross-cut nozzle, applying it to the PCB before it atomizes. This technique results in a leaf shaped pattern of material. The usable application point is from the nozzle to just above the widest point. Film coating is most effective when using materials with a viscosity less than 150 cPs, as the minimum film build increases with material viscosity. Film thickness of 1 to 8+ mils is easily attainable. Solvent based materials work exceptionally well with the cross-cut nozzle and this is the most prevalent method of selective coating used in Europe and Southeast Asia.

Many times a single board requires more than one dispense method for proper coating. For these cases, multiple applicators, or preferably an applicator with multiple mode capability is used. A tri-mode applicator allows maximum flexibility when processing boards that



SwirlCoat applicator dispensing in “bead” mode require different types of coating or coating thickness in the same dispense cycle.

Bead mode is a single stream of material dispensed through a nozzle. 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 provide a picture frame around an area of coating. Bead mode may also be used with a separate applicator in a dam and fill mode. Bead mode can be used in conjunction with assisting air to push material under tall components such as connectors, relays or transformers. A short duration bead in a stationary location produces a spot of material excellent for coating single points close to keep out areas. To ensure accuracy, the dispenser should be zero-cavity to minimize the material volume outside the shut-off. This will reduce drooling and stringing that can occur with a needle tip.



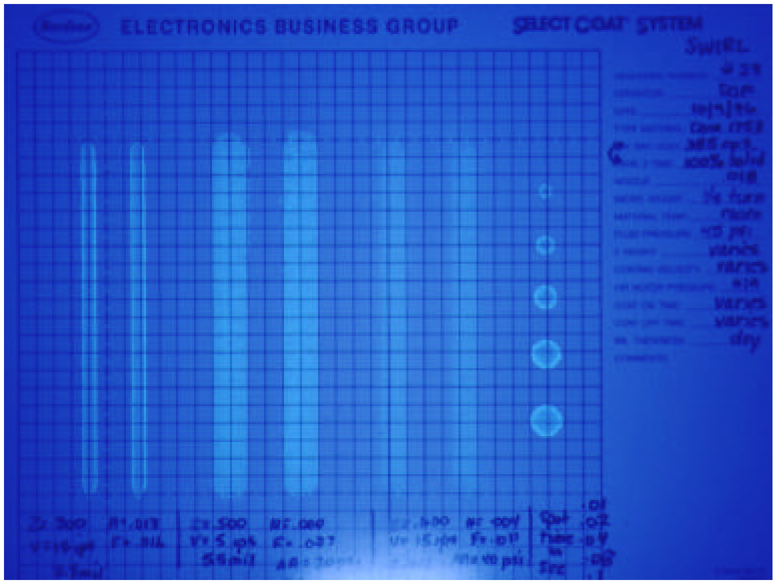
SwirlCoat applicator dispensing in "mono-filament" mode

By adding assist air around the bead, two separate modes may be developed: Monofilament and Swirl Spray modes. In monofilament mode, a single strand of material is spun on its axis by the shaping air as it exits the nozzle. As the material stream spins away from the nozzle, it stretches and becomes unstable, forming into a conical shaped looping pattern. Monofilament mode provides excellent uniformity of build, excellent edge definition and film builds from 3 to 10 mils.

By increasing the assist air pressure and velocity, the material begins to atomize into a swirling conical pattern. This swirling pattern is held together by centrifugal forces allowing a controlled atomized dispense while maintaining excellent edge definition, overspray control and uniformity of build.

To improve the flexibility or cycle rate of a single coating cell, dual applicators may be added. Two applicators add flexibility in applications such as the previously mentioned dam and fill, or a primer coat followed by a standard coating application. The simultaneous coating of two identical boards with dual guns can improve throughput by as much as 45-50%. Dual tri-mode applicators add even more flexibility, enabling the user increase both cycle rate and throughput.

SwirlCoat applicator dispensing in "swirl-spray" mode



Calibration Test Card Showing Three Coating Modes: (from Left to Right) Bead, Monofilament, and Swirl

<u>Safety</u>

Safety is a serious and important aspect of the coating process. The use of solvent-based materials requires that the proper safety procedures are 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.

There are two approaches to preventing hazardous conditions inside of a coating environment. Building the equipment with intrinsically safe parts and / or managing the amount of volatiles present at one time.

Equipment built with intrinsically safe parts is expensive and therefore not provided by some conformal coating equipment manufacturers. The management of potentially explosive solvent vapors and fumes can be achieved with a properly engineered air management system. The use of exhaust is a must with solvent-based material and with some 100% solids materials. Exhaust used with non-flammable material is also important to eliminate offensive odors from the plant environment. The correct amount of air flow in combination with the 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 will have the proper spill containment. Even if boards are not being coated with a solvent-based material, the equipment must accommodate the chance that a flammable cleaning solvent may be used.

Engineering a selective conformal coating system involves the correct and appropriate interlocks to insure an operator's safety. The electrical and pneumatic circuits should be designed and manufactured so that they are separate.

Equipment

The most important factor in any process is repeatability. As long as a process is repeatable the manufacturing process will remain under control. Therefore, a selective conformal coating machine should provide repeatability. When divided into its individual parts, a selective conformal coating machine consists of a dispenser, robot, controls and software. All of these parts should work together to deliver maximum repeatability.

The dispenser should be capable of turning on and off in a matter of milliseconds and provide a well-defined pattern. The fast response time of the dispenser in parallel with integrated software will assure that the coating patterns are placed on the product in a repeatable manner. If this is not done correctly, patterns will be placed inconsistently and the amount of material in the length of the pattern will vary.

The robot needs to be capable of moving the dispenser in three axes according to a programmed set of moves and instructions. The robot's specifications are important especially repeatability. Velocity, payload and acceleration are all important numbers in determining throughput, but keep in mind the process is only as fast as all of the parts allow it to be. Therefore, even if the robot is capable of 40 inches per second (ips) most dispensing processes will only apply material successfully at approximately 15 ips.

The software plays an important role in the overall process. Although the software is invisible while running production, it is an important variable in the success of the coating process. The ease-of-use of the software coupled with flexibility allows the programmer to attain the best possible coverage of the PCB.

The software should be logical in the commands and be fully integrated into the selective conformal coating process. Programmers or operators should not have to memorize codes or commands to determine when to turn the gun on or off. The commands should be descriptive to the point that the programmers can concentrate on spending time getting the best coverage rather than looking up or memorizing codes.

The integrated software, controls and dispenser should all complement each other and work together to provide repeatable consistent coating thickness and patterns. A system that turns a dispenser on, moves it around the board to coat areas and then turns the dispenser off would put material on the board at preprogrammed locations, but would not allow for consistent film builds. The film build would be higher at the beginning and end of each pattern due to the acceleration and deceleration of the robot. It is imperative to accelerate to a constant velocity, turn the dispenser on, dispense at a constant velocity, turn the dispenser off, and decelerate in order to achieve consistent film builds.

The system should also be capable of easily integrating into an electronics assembly line. SMEMA communications upstream and downstream is a must. With the current rate of product introduction, it is essential that the integration of today's equipment be as simple as connecting one connector for upstream an one for downstream and completing the handshake.

Summary

While there are several methods of applying conformal coating, selective coating equipment offers the most flexibility in processing different products and materials. The selective process also offers the most cost-effective solution as it reduces material waste and labor cost, while increasing throughput. The selective process is also safer and is more environmentally friendly.

When evaluating selective conformal coating equipment, the most important factor to consider is dispense head technology. The quality of the coated board is most affected by the dispenser used to apply the material. Flexibility, durability and consistency of the dispenser are most critical. A single dispensing valve that offers multiple modes will meet the widest range of production requirements. A multiple mode dispenser will offer flexibility to contract manufacturer and OEMs allowing them to accommodate many different board designs and different material types as well.

The choice of equipment should also include consideration of system hardware and software integration. Software should be written to support the conformal coating application and menus should contain easy, logical commands that an operator can understand. Software should also control the dispensing to allow consistent material deposition from start to end on each coating pass.

Because conformal coating requires a great deal of process knowledge, including an understanding of material characteristics, curing and in-line integration issues, the user would be wise to select an equipment supplier that provides comprehensive service, application engineering, operator training and ongoing support.