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Automated Cleaning of Electronic Components

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Environmental and operator safety concerns are leading to the elimination of trichloroethylene and chlorofluorocarbon solvents in cleaning processes that remove rosin flux, organic and inorganic contamination, and particulates from electronic components. Present processes depend heavily on these solvents for manual spray cleaning of small components and subassemblies. Use of alternative solvent systems can lead to longer processing times and reduced quality. Automated spray cleaning can improve the quality of the cleaning process, thus enabling the productive use of environmentally conscious materials, while minimizing personnel exposure to hazardous materials. We describe the development of a prototype robotic system for cleaning electronic components in a spray cleaning workcell. An important feature of the prototype system is the capability to generate the robot paths and motions automatically from the CAD models of the part to be cleaned, and to embed cleaning process knowledge into the automatically programmed operations.

I. INTRODUCTION

Today's environmental and operator safety concerns are leading to the elimination of trichloroethylene (TCE) and chlorofluorocarbon (CFC) based cleaning processes. Present processes depend heavily on these solvents for manual cleaning of small components and subassemblies. For example, manual spray cleaning is widely used for cleaning electrical and printed circuit assemblies at AlliedSignal in Kansas City (ASKCD), one of the DOE production facilities. However, this cleaning technique is operator dependent, exposes workers to hazardous solvents, and lacks the repeatability required for high reliability components. Historically, electrical components such as radars, cables, and programmers have been manually spray cleaned using TCE followed by isopropyl alcohol. Cleaning removes rosin flux, other organic and inorganic contamination, as well as particulates. Inadequate cleaning can affect component stockpile life and functionality. Thus, effective cleaning is required to achieve the required reliability of equipment, particularly for printed circuit assemblies.

Although safety precautions and engineering controls are in place, the potential for operator exposure to hazardous materials still exists. ASKCD is currently developing a number of processes which can result in elimination of TCEs and CFCs for cleaning. However, spray cleaning processes which use substitute materials may not clean adequately with minimal waste. Since manual spray cleaning relies on the operator's skill, solvent usage and cleaning effectiveness vary from operator to operator. The use of more environmentally benign cleaning solutions thus necessitates improved quality control in the cleaning operation -- such as spray uniformity, consistency, control, and repeatability, without boredom and fatigue factors -- which computer-controlled robotics can offer. Thus, automated spray cleaning will improve the quality of the cleaning process, and thereby enable the productive use of environmentally conscious materials. Also, automated spray cleaning minimizes personnel exposure to hazardous materials. Further, automation of the cleaning process can lead to optimization of the process, which can minimize the waste stream and increase solvent effectiveness. This paper describes the prototype system under development for the automated cleaning of electronic components mounted to printed circuit boards.

A significant drawback to the use of robotics in this type of application is the labor required to teach robot paths. This is especially true in the case of DOE production of parts, where small lot production runs are typical. In the case of small businesses, the labor required for robot programming can represent a prohibitively large, continuing investment that may preclude any benefit gained by automation. For example, to manually generate the robot program to clean a circuit board will take several hours; for more complex parts, several days of programming may be needed. Even for identical parts, changes to the cleaning process require reprogramming. As a result of these concerns, we have focused particular attention on methods to automatically plan and program the robot's motions. By using CAD models of the part to be cleaned, one should be able to combine the process requirements together with the engineering data for the part and the models of the robotic workcell to generate robot motion programs automatically and nearly instantaneously. Unlike spray painting, the spray cleaning process is complicated by the requirement to clean the most difficult areas, such as the hidden area beneath a surface mounted integrated circuit chip. This requires intelligent integration of cleaning process rules and specifications with 3D model geometry in order to automate the programming of paths that precisely position the cleaning stream and avoid obstructions. The use of models to automate path planning and robot programming simplifies and accelerates the automation process, and adds great flexibility by rapidly accommodating changes in part design or cleaning process specification.

II. CLEANING OF CIRCUIT BOARDS

A particularly difficult technology to clean during manufacture is that of surface mount devices. This is due to the very small clearance between the device and the mounting board, typically only 0.05 mm. Solder flux, paste, and contaminants become trapped beneath surface mount devices during installation, and spray cleaning action alone is not effective in penetrating under the chip to erode residual contaminants. For the precision cleaning needs of the DOE, all contaminants must be removed in order to ensure high reliability operation over long time periods.

Several alternative solvent systems are being developed at AlliedSignal in Kansas City to employ environmentally-conscious alternative solvents for cleaning of electronic circuit boards [1]. Among these is the use of an aqueous solvent that is applied manually using a high pressure microdroplet spray system [2]. Details of the spray solution and application may be found in the reference. The cleaning fluid uses a saponifying agent to clean residual solder flux contaminants. The combination of high pressure microdroplet spray streams and a surface tension reducing agent is important for penetration of the cleaning fluid beneath the surface mount device. Even so, the spray stream needs to be directed with reasonable precision around the perimeter of each device in order to direct the spray stream to penetrate and flow under the device.

Laboratory studies have determined that it takes many times longer for equivalent spray cleaning using the alternative solvent as opposed to chlorinated solvents used in the past, such as trichloroethylene. In the case of a prototype surface mount device board, approximately eight to ten minutes were required for cleaning, vs. thirty seconds with the original solvent. During the entire cleaning period, the spray stream needs to be directed at the edges of the devices to develop the process of fluid erosion, chemical reaction with the flux residue, removal of the contaminants, and fresh application to a new area of residue. Revisiting an area already sprayed following a time delay appears to be an important element of an effective cleaning method. In addition to these constraints on the cleaning process, the spray nozzle generates a significant back force due to the high pressures used, making the process physically fatiguing when done for several minutes. For these reasons, an automated process can be used to maintain or improve the quality of the cleaning when changing to an alternative solvent. By employing an articulated robotic arm to manipulate the spray nozzle, the cleaning method can be precisely controlled and repeated, accounting for the proper speeds and delays over long time periods without human fatigue. The use of a robot thus enables the use of the alternative solvent in this application. In addition, by automating the process, part handling can be reduced, which leads to fewer cleaning steps in the overall process.

A demonstration circuit board using a variety of sizes of surface mount devices was developed for process investigation. The board, shown in Fig. 1, incorporates a transparent sapphire substrate to allow real-time examination of cleaning action and non-destructive post-cleaning analysis of the cleaning process. The overall board is 50 mm by 50 mm square. The largest surface mount device is 25 mm square; the smallest is a square 5 mm on a side. Fig. 2 shows, from the back side of the board, the spray cleaning fluid stream as it impacts the board. To cause effective fluid flow beneath each device, the spray stream must be directed to impact the board at the edge of each device.

Fig. 1. Demonstration circuit board with surface mount devices mounted on a transparent sapphire substrate.

Fig. 2. Manual spray cleaning of board in Fig. 1, viewed from back side of board looking into spray cone.

III. CLEANING PROCESS SPECIFICATIONS

The process for spray cleaning of surface mount devices on printed circuit boards typically includes washing, rinsing, and drying. These functions use different solutions and spray nozzles, and different types of spraying paths may be executed. Path parameters of importance are the nozzle speed, nozzle tilt with respect to the board surface, standing times (which can depend on the size of the component device), standoff nozzle distance, etc. The geometry of the spray stream pattern from the nozzle is an important element for repeatably modeling the spray function. Here, angle of spray, spray pattern configuration, and width of the spray stream annular ring (as it impacts a flat surface) are important parameters.

Depending on the size of the component device, edge spraying may need to be repeated multiple times. Another important parameter is the spacing of leads on the device, as this determines the surface area available for flow penetration beneath the device. Further considerations are the separation distances between devices, and the height of nearby circuit elements. Both of these can dramatically limit the volume of fluid available to flow beneath a device, either by obstructing the spray stream or by limiting the surface area of the mounting board that is impacted by the stream. All of these parameters need to be considered for the rule-based planning of the cleaning path.

We have worked with AlliedSignal process engineers to define specific classes of motions (paths) important for effective spray cleaning. Some are effective for gross cleaning of the entire board. These include a board perimeter path, and a raster path across the board. Other path types were identified that are specifically designed to clean elements such as surface mount devices. A component perimeter path directs the spray stream inward to the device (underneath it) while traversing around the perimeter edges of the device. A step function path was designed to flush fluid in one direction across a board while stopping at the leading edge of each device. This will perform a final flushing action to remove deposits from underneath each device without contaminating cleaned areas of the board, or during the final air drying.

IV. PATH PLANNING

The path planning software uses CAD models of the part to be cleaned and rules describing the process to plan and generate robot spraying paths to accomplish the component cleaning task. Rules are an important element of the path planning because models and geometric information alone are not sufficient to clean the hidden surfaces. In the planning, empirical rules are used to develop path strategies that clean the hidden surface areas beneath the devices. To differentiate hidden and exposed surfaces, and to plan robot motions to clean exposed surfaces, geometry-based path generation is used. Details of the geometry-based planning are described in a related paper [3].

For the rule-based planner, a CAD model of the part is created using the Intergraph EMS solid modeler. Software written in the Intergraph PPL programming language is used to extract the relevant part geometry from the model. The output is a list of part geometries which, when combined with cleaning rules and parameters for nozzle distance, angle of attack, and other process specifications, leads to a programmed robot path. The cleaning parameters may be specified or modified by the process engineer using a graphical interface developed for the modeling/programming workstation. The operator can select various classes of cleaning processes and paths. The robot tool path points are generated from the selected path sequence, the spray cone specification, and the part geometry, in a few seconds.

The user then simulates and previews the robot's motion using a graphical simulation to verify workcell reachability and collision-free paths. Fig. 3 shows a view of the workcell simulation from the computer workstation. In this simulation, the motions and shapes of the robot and spray stream are modeled and displayed relative to the modeled circuit board from Fig. 1. Once satisfied with the path, the operator directs the software to generate and download the robot program to the robot controller, and to execute the program for actual part cleaning. Software was written to translate these path points and process specifications into the robot controller's native program language.

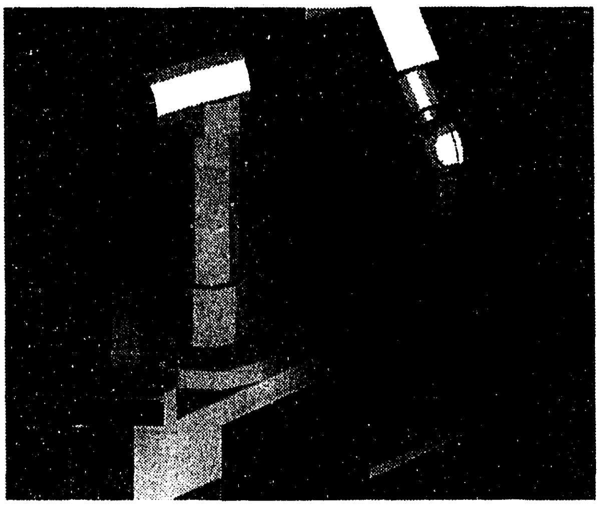

Fig. 3. Robot workcell simulation model showing robot spray cleaning nozzle, spray pattern, and demonstration circuit board.

Fig. 4. Spray cleaning workcell with robot and workcell controller.

V. ROBOTIC WORKCELL

We have developed a spray cleaning workcell to demonstrate the automated programming method and to prototype an automation solution for cleaning of printed circuit boards. In addition, the robotic spray cleaning workcell provides a controlled environment for continued cleaning process investigation and development. The workcell is shown in Fig. 4. The workcell consists of an enclosed spray cleaning booth with a robot, spraying tools, and a part mounting fixture mounted inside. Gloveports are available for manual access. A part transfer door is on the side of the workcell.

Beneath the cleaning area is a cabinet which houses the plumbing and heating systems for the workcell. A control cabinet houses the control panel and a PLC-based system which controls the valves, heaters, and pumps for the spray cleaning process. Either manual or robot-programmed actuation is available. The cleaning solution bath may be heated. Currently, the spray cleaning solution is applied at 140°F at a pressure of 450 psi. During rinsing, the fluid is applied from a rinse tank or an external supply at 100 psi. The nozzle used for each generates a hollow conical spray pattern with an included angle of about 60°. Drying is performed with a planar nozzle using 80 psi heated or ambient temperature air or inert gas. Reference 2 provides additional information on the cleaning process.

The robot used in the system is a six axis Kawasaki 260 with a payload capacity of 1.2 kg. To prevent moisture penetration during spraying, a number of additional measures were employed. The robot is a cleanroom model, which uses sealed joints and an epoxy-based coating. In addition, the interior of the robot arm is pressurized slightly to prevent moisture from entering any remaining openings in the robot, and to purge humidity from the robot's interior. Finally, silicone sealants were applied to the robot arm enclosure to reduce leakage. During prolonged operation, flexible boots, skirts, and shields may be employed on the robot arm.

VI. SUMMARY

To provide alternative cleaning systems in today's regulatory environment, several substitution solvents and alternative technologies are being developed. For precision spray cleaning of electronic and mechanical components during manufacture, alternative solvents require longer times and better control during application than predecessor solvents. Automation offers a method for removing workers from fatiguing and hazardous operations while providing the necessary control to perform precision motions to ensure a quality-controlled process. Automated methods to plan robot motions and generate robot programs from the process knowledge and engineering information of the parts is an important element of a cost-effective system. The use of models to automate path planning and robot programming simplifies and accelerates the automation process, and adds great flexibility by rapidly accommodating changes in part design or cleaning process specification.

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