The advent of surface-mount technology ushered in reflow as the primary soldering process, overshadowing wave soldering. However, not all components are suitable for heating in a reflow oven. Some cannot withstand the heat of that process. Many other components are still not surface-mountable; they have pins for through holes. However, more devices are increasingly being assembled using the selective soldering process.

In the electronics industry, automation has come to dominate assembly processes. For example, in automotive manufacturing, quality assurance efforts have eliminated hand soldering, whose results depend on human skills and technique and are not as reliable or repeatable as an automated system. In many automotive applications, dependability and quality are critical.

Some selective soldering can be achieved on conventional wave soldering machines, with very reliable results. But this approach requires expensive customized pallets to protect and cover the surface-mount components during soldering.

Just as pin-in-paste reflow soldering is not always an option, so also hand soldering is not reliable and selective wave soldering pallets are costly and require much handling and cleaning. These inadequacies and others created the need for a new process.

This new process features robot selective soldering machines, which offer greater flexibility for board designers. The most advanced of these machines can solder under different angles, rotate boards, optimize soldering parameters (contact times, dip speed and exit speed) for every individual solder joint, and even vary the application of flux to specific board areas as required.

Most of this functionality is not available in wave, reflow or hand soldering. Because this new selective soldering process incorporates new technology, most process engineers do not know how to effectively use it for their products and what its limits and specifications are.

The first article in this series described the selective soldering process in detail. This article will discuss the process parameters and specification limits that are needed to achieve reliable, robust selective soldering. Recommendations will also be provided regarding allowable parameter tolerances. Also described will be the importance of process capability ($C_p$) for defining the reproducibility of a process.

Quality Programs

Selective soldering is already widely used in the automotive electronics industry, which also uses quality assurance programs such as ISO QS9000 and six sigma. To implement these programs, failure mode and effects analysis (FMEA) and machine capability studies are needed. Vendors that supply products and services to the automotive industry frequently have to prove that their assembly processes, including selective soldering, are under control.

FMEA programs include systems, design and process areas. The purpose of a process FMEA is to analyze manufacturing and assembly processes and identify potential product failure modes. A FMEA for the selective soldering process, implemented before high-volume production begins, is advantageous in that the machine configuration can be optimized and calibrated. Additionally, training programs can be determined in advance.

FMEA attempts to identify potential failures, plus their effects, causes, how to avoid them, and what controls are in place to recognize them. Apart from the failure analysis, the process requirements must also be understood; identify the process parameters, their accuracy and limits to achieve good soldering over a longer period of time.

Determining Process Capability

Process capability attempts to answer the question: Can we consistently meet customer requirements? The primary limitation of process
Selective Soldering Sub-Processes

Selective soldering can be divided into five basic sub-processes: conveying, fluxing, preheating, board handling and soldering.

In addition, controls and software are used to link the various processes together. Creating a program for an assembly (teaching) can be done off-line, but requires fine-tuning before mass production starts. Computer-aided design (CAD) and Gerber data can be used, but the required data must be filtered out. Using the machine’s integral camera is, in most cases, a faster and more efficient programming method.

The distribution shape of each process parameter (variable), indicating the frequency of values from different ranges of the parameter, is important in process control. Typically, an engineer is interested in how well the distribution can be approximated by normal distribution. Visual examination of the measured data is achieved using a histogram (Figure 1).

The procedure begins by drawing 100 random samples of each parameter that is of interest for good soldering. For the flux unit, the parameters include the x and y positioning of the robot and the amount of flux sprayed though the dropjet nozzle. Each parameter should be checked to determine if the distribution of all the collected data follows a bell-shaped distribution curve. Either the Kolmogorov-Smirnov (K-S) test or the normal distribution plot can be used to determine if the data are accurately modeled by a normal distribution.


capability indices is that they are meaningless if the data have not been obtained from a controlled process. The reason is simple: process capability is a prediction, and one can only predict a process that is stable. To estimate process capability, one must know the location, spread and shape of the process distribution.1

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- Flux application has two factors: the location of the flux application, and the amount of flux to be applied. The smallest single flux droplet diameter provided by a dropjet fluxer is larger than 2 mm. Therefore, the positioning of the flux on the PCB should have an accuracy of ±0.5 mm to guarantee that the flux always covers the joint area.

The tolerance of the flux amount to be applied is directed by the flux suppliers. Their data sheets should mention the amount of flux necessary to do the job. Often, a safe tolerance of at least 100 percent is an advised application value. For example, when a value of 12.5 g of flux per m² is advised, a flux amount up to 25 g/m² is allowed, without interfering with the quality of the process.

Example: Flux Robot X-Positioning

The following example describes how to measure the process capability (Cp) of a flux robot’s x-position relative to the PCB. For positioning accuracy, the selective soldering machine uses laser equipment, which enables the process engineer to monitor the robot’s placement accuracy within ±0.01 mm. The data from each robot cycle, during which all robot movements are made, are saved in a file during the test.

For this example, the K-S number is 0.84, which indicates a normal distribution (Figure 1). The normal distribution plot for the x-position of the robot flux unit shows a relatively straight line (Figure 2). From this, we can calculate the machine capability:

\[
C_p = \frac{(USL - LSL)}{(6 \times \text{Sigma})}
\]

with USL being the upper specification limit and LSL being the lower specification limit. Because we want to be very accurate in applying the flux, we specify the following values for USL and LSL (from Figure 2):

\[
USL = 35.58 + 0.15 \text{ mm} = 35.69
\]
\[
LSL = 35.54 - 0.15 \text{ mm} = 35.39
\]
\[
C_p = \frac{(35.69 - 35.39)}{(6 \times 0.0112)} = 4.46
\]

Conveying

In selective soldering, the conveyor is essential for in-feed and also for carrying the board to several stations where it stops for process actions. The conveyor speed is not an essential process parameter here. However, the other process steps may have a direct effect on process quality.

Fluxing

The fluxer module consists of an x,y robot that moves a dropjet nozzle to the sites to be soldered. Fluxing in selective soldering is totally different from fluxing in wave soldering. In wave soldering, all flux applied on a board will go through the molten solder. In selective soldering, only selected parts of the board will be in contact with the solder. So, if flux is applied to the wrong area, it will not be washed off and will remain on the board after soldering.

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A value of $C_p \geq 1.66$ indicates that the process is well under control.

**Preheating**

Preheating in selective soldering is not intended to reduce thermal shock, but rather to pre-dry the flux to remove solvent and bring the flux to the correct viscosity before entering the solder wave, as is often recommended. Preheating to support heat transfer during the soldering process is also not a key issue here. Board material thickness, flux type and component layouts determine preheat settings.

Different theories exist for preheating in selective soldering. Some engineers like to preheat the board before fluxing, whereas others solder without preheating.

Preheat temperatures should be within a target range between, on the lower end, the solvent evaporation temperature and, on the upper end, less than the temperature where the flux begins to decompose before soldering begins. The flux supplier’s data sheets should provide the necessary information.

Additionally, the component to be soldered should not be overheated such that it is damaged or its reliability compromised. Again, check the component data sheet. A rule-of-thumb can be a solvent evaporation temperature of $\pm 20$°C.

**Board handling**

Due to the wetting forces acting on a wettable surface when it is in contact with the molten solder, a sound solder joint can be established when the full lead and more than half of the solder pad diameter are in contact with the solder. If the nozzle size is appropriate, a tolerance of $\pm 0.5$ mm from the center of the joint in the nozzle is acceptable without compromising joint quality. This tolerance is also acceptable for fluxing.

The location of surrounding components may affect positioning tolerance because surrounding components cannot touch the solder nozzles. In expressing robot system limit parameters, a positioning tolerance of $\pm 0.15$ mm is needed for the robotic system to avoid damaging or washing off components with molten solder.

**Soldering**

In the soldering process, several parameters are noteworthy. Good wetting of the solder joints is important; so the products to be soldered must have good solderability prior to soldering.

Wetting is a result of contact time and solder temperature working together. Instability of a solder wave will show up in variations of the contact time. The addition of nitrogen will improve the solder’s wetting characteristics.

As long as the solder temperature is well above the solder’s melting temperature, a tolerance of $\pm 5$°C is allowable. The safe operating area for soldering is normally within a range of 20°C. Two different soldering principles apply to selective soldering. The first involves the use of a single nozzle, for either a single drag wave soldering process or a dip soldering process. Drag soldering is typically done under an angle of 10°. Dip soldering with this nozzle can be done horizontally or under an angle.

One notable characteristic of the single nozzle is that the solder overflows on one defined side of the nozzle. A typical solder temperature for this nozzle is 280°C. This temperature is higher than in wave soldering because only part of the assembly runs through the molten solder. However, more heat is added into the board with a small nozzle to compensate for heat flow to the surrounding board area.

The second type of selective soldering is multi-dip wave soldering. This technique uses an application-specific plate with a series of nozzles mounted on it, exactly positioned relative to those areas on the board that need to be soldered. The board is held horizontally in a gripper and dipped down to the solder nozzles. For most multi-dip processes, not enough space is available to let the solder overflow, so higher soldering temperatures are needed; typically around 300°C.

Machine capability analysis monitors the robustness of the machine to keep the solder temperature at the setpoint under control. The solder temperature shows a sinus curve around the target. This result is from the PID control of the heating elements on the solderpot. Due to this configuration, a non-normal distribution of the
Soldering is a function of contact time and solder temperature. The soldering time in common wave soldering may vary considerably, without interfering with solder joint quality. The soldering time depends on the layout, because that will affect the solder separation conditions. Common tolerances on the dwell time are ±0.5 seconds. Total soldering time includes the dwell time and the solder separation time. For the last parameter, no statistical data are available.

To produce “clean” data, a dummy component with a non-wettable lead must be used. This procedure is also how dwell time measurements are made on wave soldering machines; by using a measuring board.²

All data are collected with nitrogen covering the solder wave. In selective soldering, nitrogen is required to eliminate oxides on the solder surface. Nitrogen also improves the wetting, so it is an additional parameter to be controlled.

**Example: Contact Time**

The following example describes how to measure the process capability ($C_p$) of the contact time. For a single drag wave process with a 6-mm nozzle, the contact time was set at 2 seconds (2,000 msec). The results of the 100 collected times are shown in Figure 3.

The $C_p$ value of 18.5 is relatively high due to the wide range between the upper and lower specification limits. This value is determined by the process and is based on experience. For some processes, a minimum contact time of 2 seconds is needed for good wetting. However, a contact time that is one second longer (3 seconds) also fits. So, selecting a range of 1 second (1,000 msec) between the upper and lower specification limits is fair.

**Nitrogen and Selective Soldering**

The use of nitrogen will assist the single drag wave soldering process by creating an environment with a lower oxygen level. The nitrogen atmosphere reduces the oxidation of the solder wave and improves the wetting of the parts to be joined with solder.

For the multi-dip wave soldering process, the nitrogen also reduces the oxide formation on the solder wave, especially during flushing of the solder waves before bringing them to their setpoints. As soon as the covers are opened, air will come to this area, which will displace the nitrogen. Therefore, nitrogen is not necessary with a very low oxygen level. A nitrogen purity of greater than 99 percent is sufficient for this application.

The nitrogen consumption for the single drag wave process should be set at 20 l/min for the standard 6-mm nozzle. For the multi-dip wave process, the nitrogen flow should be set at 120 l/min.

Once the correct nitrogen flow is determined, a constant and reproducible flow is required, although some deviation in the nitrogen amount will not detrimentally affect the soldering quality. The nitrogen flow supports the process, especially at the point where the soldered joints leave the solder wave, by reducing spikes and flags. The effect of nitrogen very much depends on the amount of flux used and the PCB layout. Possibly, a good solder quality can be achieved if no nitrogen is used at all. For these reasons, a rather high tolerance range is allowed for the nitrogen flow in this process.

Thus, the criteria for the nitrogen is selected as a target value ±10 percent. So far, machine capability studies have shown that the processes are within specification.

**Conclusion**

After defining all parameters in selective soldering that affect solder quality and defining their upper and lower specification limits, machine capability analyses can be effectively used to quantify process control. Periodic monitoring of the most important parameters with x-r charts will improve quality and warn of drift and out-of-control situations. Quality tools such as FMEA and machine capability analysis provide critical views of the process, helping to improve it and keep quality levels high. The results are less defects and reduced cost overall.

The final article in this series, to be featured in the December issue, will describe how selective soldering can be used in several challenging applications.

**References**


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