Step 2: Process Control

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Statistical process control (SPC) is a much discussed science that has been applied (and misapplied) to electronics assembly for many years. This article discusses the development of the "true" requirements of a successful SPC program, including real-time data analysis and operator empowerment plus numerous examples using typical process data values to aid understanding.

The most fundamental objective of electronics assembly is profitability through production of functional electronic products at a specified quality level. Also basic is the necessity to minimize, or eliminate, defects in the products throughout operations, such as the common solder paste printing defect. This applies equally to quality problems identifiable in the factory as well as those in field failures. Thus, it is common sense that any and all techniques that can improve quality should be evaluated and applied rigorously whenever possible to improve profitability. SPC is one technique (developed in 1924 by W.A. Shewhard) to assist this effort.

Discovery vs. Prevention

All too often, the non-value-added operations of inspection and testing are focused on "catching" defects before they escape the factory rather than preventing their occurrence. Often, inspection is implemented at the end of the assembly process. If defects are identified from a problem early in assembly, such as with solder paste or stencil printing, many assemblies already will have been affected despite immediate corrective action having been applied. SPC, when implemented correctly, focuses on monitoring (either during or immediately after) each process and improving it to effect reduction, minimization and, ultimately, elimination of such defects.[1]

SPC also can be a powerful sales/marketing tool for contract manufacturers (CM). Increasingly potential OEM customers are asking, "How do you ensure quality products?" or "How do you guarantee that defects will not occur in my products?" Demonstrating a comprehensive SPC program can be a valuable tool in satisfying those concerns and requirements, not to mention that defect reduction will improve "bottom line" profitability while rendering the CM more cost competitive.

What Is SPC?

SPC is a system of statistical methods that determine process consistency and capability. It is based on the measurement of actual quality performance of a process, continually or at regular intervals. The methods incorporate the following sequence:

Process Parameters

SPC's foundation is a thorough definition of the process in terms of quantitative specifications that are known to determine product quality. Specifications are not single, discrete values. Rather, they must be defined as ranges consisting of a minimum, maximum or both. The "peak temperature" of a product during reflow typically is specified at 205° to 230°C, within which all solder joints must fall. In traditional SPC terminology, these are termed "specification limits," and the acceptable range between the high and low specifications is called the "process window." It is important to note that peak temperature is a parameter that is measured directly on the product as opposed to (in this example) the heater temperature in an oven's reflow section, the temperatures on a calibration vehicle or the temperature of a "standard" test board. Further, the temperatures should be measured in real-time on the solder joints of the actual products.

Data Collection is carried out as products are produced. Herein lies a fundamental issue that historically has thwarted effective implementation. Too often, data gathering and recording within the manufacturing environment are viewed as non-value-added activities that reduce productivity and waste time. Such perceptions or prejudices can form a basis of excuses for not collecting data — unfortunate because SPC's real power and utility only are attained when a consistent historical record of process conditions is recorded and analyzed to reveal variation trends over a wide base of operating conditions. Further, proper application of these techniques will ensure the statistical validity of the data and the resulting analysis.

Data Analysis

Once collected and recorded, data must be consolidated and analyzed before any value to operators, supervisors, process engineers or management can be derived. Generally, SPC analysis consists of computing averages and ranges, comparing them with historical values and making statistical predictions and judgments. One of the most basic of these analyses separates variations into random (common cause) and non-random (assignable) patterns and quantifies their respective magnitudes. This information can stabilize and optimize the process during initial setup and identify changes (i.e., degradations) under continuous operation. It is the outputs of such analyses that provide the information on whether the process is operating correctly or that variations are occurring, which may generate defects.

One of the technique's more sophisticated capabilities is to observe ongoing trends (in performance) and to identify variations before performance exceeds specification limits. The data recording and analysis results initially are used to ensure that the process is "in control," which requires that it display only random variations and that the levels of variation are within product quality requirements. For example, reflow soldering would imply that the oven is operating correctly with an appropriate recipe for a specific assembly.

The lack of timely analysis of collected data and communication of results to the appropriate, responsible personnel comprises the largest source of a judgment of inadequacy or outright failure in SPC system implementation. Results must be made available as quickly and as clearly as possible to facilitate corrective action and to minimize or prevent defects. Graphical outputs in the form of "control charts" have been found to be one of the most effective methods of communicating the results of SPC data collection and analysis. The formats are simple and straightforward so that all levels of personnel can be readily taught to read and understand the information and the process implications. Typically, new data points are added to the charts after each set of data is recorded and analyzed. Control limits define the range in which all data should fall based on historical (not desired or theoretical) data for the operating process. Specification limits can be plotted similarly as lines on the same chart. Completing the definition of "in control," acceptable levels of variation are indicated when the control limits lay inside the specification limits. In Figure 1, a typical process (peak reflow temperature) is "in control" with the limits (212° to 224°C calculated at three standard deviations) well inside specification limits (205° to 230°C).

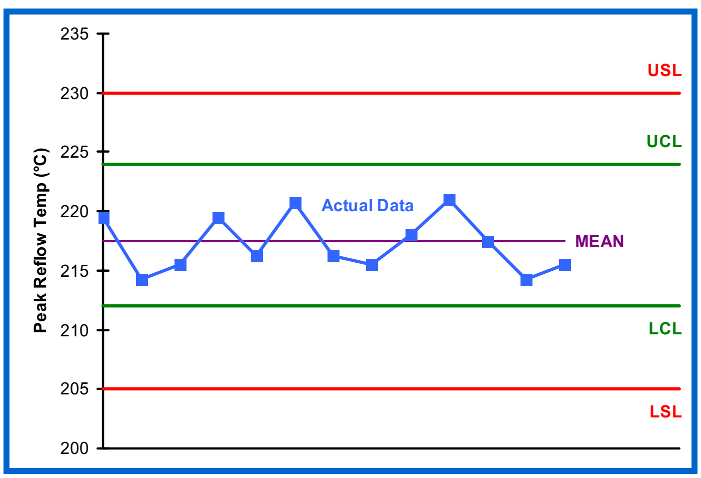

FIGURE 1: An SPC-derived control chart (peak reflow temperature). Such charts are effective means of communicating the results of SPC data collection and analysis.

For certain equipment, such as reflow ovens, the intervals between failures can be quite long, e.g., measured in months, rendering it easy for operating personnel to stop paying attention to process performance. Within an SPC environment, those events are defined as "assignable causes" of variation and are identified readily by the analysis of the appropriate product specification parameters. A properly operating, real-time SPC program can minimize such defects by alarming those responsible upon the occurrence of out-of-spec performance or, ideally, by identifying a trend and warning before defects occur. This provides particular advantages to products, (e.g., area-array packages, such as ball grid arrays [BGA]) for which soldering defects are difficult to find and repair.

SPC Implementation Requirements

Measure Actual Process Parameters

For SPC to be most effective, these must be the critical parameters that truly define product quality and not just those that are easy or convenient to measure. Often this requires measurements to be taken on the actual product during or after the process operation (such as peak reflow temperature) at a specific location on a printed circuit board (PCB). Certainly, it is easier to monitor the heater temperatures in the reflow section of the oven — perhaps using the sensor already part of the oven controls. But it will not provide the level of process quality control as actual product level measurements. For example, in reflow, a convection fan failure is a common example in which heater temperature measurements often are inadequate to indicate a deviation in a board-level heating profile.

Measure All Critical Parameters

A robust SPC program should monitor all parameters that have been identified as indicators of quality and for which specification limits have been established. Whereas previous sections identified the importance of performing actual product-level measurements, it still is important to monitor and control all equipment and incoming material parameters that are significant to the process.

Two dynamic material issues merit solid attention: solder paste exposure time on the stencil and temperature/humidity exposure for moisture-sensitive integrated circuit devices (MSD), for which the continuous monitoring techniques of SPC are particularly adaptable and important. Once removed from protective packaging, each reel or tray must be tracked against its IPC Class Exposure Specification Limit as it moves through the entire production cycle through final reflow. Any overexposure can result in excessive moisture absorption, potentially resulting in internal package damage, which may not be detectable until premature field failure.

The large number of significant process parameters generally results in large quantities of data to be gathered, recorded and analyzed. The reflow process alone, for example, may incorporate numerous process specifications: peak temperature, time above liquidus, preheat and reflow slopes, and soak temperature/time. Accordingly, to ensure the entire assembly's quality, it is frequently desirable to monitor those parameters at multiple locations, such as solder paste deposition height for multiple BGA's or temperatures for hottest component and coldest solder joint.

Involve Personnel at All Levels

One requirement for the success of any SPC program is the commitment by all departments to use and support the system. To reduce defects effectively, any quality system must be used regularly and diligently. A lack of commitment or support in any department or at any level can damage or completely negate the system benefits and the work of all others involved.

Operators on the production floor should be actively using the SPC systems continually even if only responding to alarms and warnings. Operators will respond and use tools they feel will help them to do their jobs better and more easily. However, they must understand the system, the information it is producing, the benefits to them in performing their jobs and the overall success to be gleaned in satisfying the customer.

Control charts originally were conceived as simple graphics that could be understood and used by any level of personnel. Training and implementation, which directly involve operators, have been shown to be effective in gaining employee "investment" in producing quality products. Some processes (especially reflow), because of their construction and operation, can run within their control limits for long periods, sometimes many months. During such intervals, it is easy for operators and even supervisors to "forget' the details of SPC programs. In today's employment reality, after several months, personnel who originally set up or were trained on an SPC system may have left for other jobs or companies. When a warning or alarm occurs, there may be no one in the area with direct knowledge of the message's meaning or of the appropriate corrective action. Similarly, when process changes are implemented, the program may not be updated properly to monitor the new products and conditions. This is particularly important in a high-mix production environment. New personnel must be trained on the proper use of any SPC system, and "refresher" courses may be appropriate for longer-term staff. Not only does this make economic sense, but also it is vital to maintaining a committed workforce.

Perform in Real-Time

To reap the maximum benefits of defects reduction (and ideally, elimination), SPC must be performed in as close to real time as possible. This applies to data analysis and decision outputs as well as the measurements themselves. If results are not available, no one is aware of problems, no corrective action can be taken and quality cannot be improved. Perhaps the best way to illustrate this point is to refocus on the cost of defects and, in particular, the economic benefits of prevention.

Using the previously described reflow convection fan problem as an example, if this malfunction results in peak temperatures below specification, every subsequent board will be defective until repairs are made. If reflow cycle times, as usual, are less than one minute, many defective products will be generated if post-reflow inspection is relied upon to identify the problem. If actual peak temperature is measured on each assembly and the results analyzed and relayed to the operator immediately, corrective action can be initiated much sooner, significantly reducing defects and repair costs.[2]

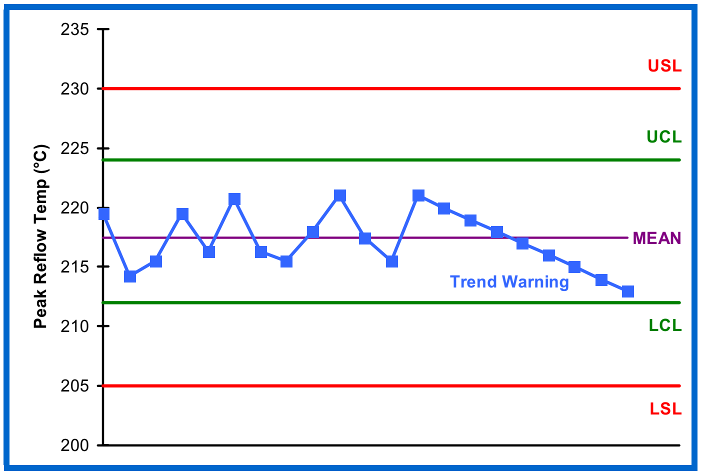

FIGURE 2: Trend warning: Seven consecutive points up or down hint of possible defect occurrence and cause to initiate process correction.

Realistic Trending

Zero defects is the "Holy Grail" for which many have at least paid lip service. It certainly is a noble (and profitable) goal and SPC possesses technology to at least move toward if not to achieve it. Standard algorithms are available to evaluate trends and define warnings that will permit corrective action before the process exceeds specification limits. Figure 2 displays a trend warning based on typical criteria of seven consecutive points either up or down.[3] Note that neither the control limits nor the specification limits have been exceeded. This example could represent the data for the convection fan failure described previously and if the warning is acted upon quickly enough, defects due to low peak temperature might be avoided. Whenever possible, trend algorithms should be augmented by empirical results of fault simulation on the actual process and products that are to be monitored. This involves artificially creating known failure modes. Follow by observing the results of the SPC measurements. This can facilitate fine-tuning of the trending functions to provide maximum sensitivity to the actual process functions and ultimately to maximize defect reduction.

Setup for Robust Operation

The most comprehensive SPC program in the world cannot produce benefits if it is not used continuously in the production facility. Two set-up problems can deter the proper use of a system: new product setup and existing product changeover. Both can occur frequently in today's CM or OEM environment. With the emphasis on quick changeover to increase equipment use time, it is very easy to overlook the SPC system if setup requires significant labor or even if it requires any separate actions at all.

Software Integration = Largest Problem

It is important to consider that all factors described must be in place to achieve the benefits of SPC. Questions as to why SPC is underused in our industry can be answered easily — the information describing process problems is not reaching the critical operations personnel soon enough (if at all) to prevent defects. All following issues can be cited to explain why the system is not running:

- The person who knew how to use it does not work at the company anymore.
- Product-level quality parameters were not being measured.
- Not all of the critical parameters were being measured.
- The correct measurements were being made but the operator was not trained and failed to react.
- The system was not "turned on" after product changeover.
- The system had correctly indicated the same problem numerous times but management did not implement corrective action.
- The correct parameters are being monitored but results are not reaching the responsible person fast enough.

All these occur, but it is the opinion of the authors that the last item is the dominant in today's electronics assembly facility. Much process control hardware has been purchased and installed — often as options on the process equipment such as 2-D vision inspection on a screen printer, along with many SPC software packages. What seems to be lacking in many locations is complete and robust software integration. Solving these integration problems with in-house personnel can be effective but it does leave a vulnerability to the "Joe doesn't work here anymore" syndrome. The advantages of a fully integrated and debugged system designed by an independent company may prove to be the best long-term and cost-effective solution.

Summary

No one questions that SPC is a useful tool that can bring improvements to any process. The reason it is not used more extensively or effectively is a widely held (but seldom voiced) feeling that it is just "more trouble than it is worth." To counter this sentiment, the real savings (in dollars) that will accrue after proper implementation must be focused upon.[4]

- It is necessary to properly implement SPC techniques to achieve its full benefits. This requires the proper and appropriate measurement of the actual, critical process parameters that determine quality — not just the ones that are "easy" to measure. Where actual physical measurements are impossible, correlated models based on real-time indirect measurements can provide a cost-effective solution.
- Perhaps the most critical factor in reaping the benefits of an SPC program is the requirement for real-time analysis of measurement data and clear output directly to the operator of the results, including trends, warnings and alarms. This is the area that most commonly is overlooked or underdeveloped in the industry and it primarily is a software issue. Data collection and analysis must proceed automatically, permitting operators or supervisors to perform their normal functions. Furthermore, the system must be robust and reliable enough for all personnel to be confident that when a warning or alarm occurs, something really is wrong and requires action.
- Dedicated and fully integrated software packages can provide the best solution to the problems of making SPC work in today's "lean and mean" production environment. Because of the multitasking that is expected at all levels, a staff has limited time. An independently developed third party package, for example, that is dedicated to a specific application can provide the out of box, complete functionality required without significant setup operations or programming (learning) by in-house personnel. ■

References

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