Implementing SPC for Wet Processes

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Statistical process control is rare for wet processes, yet OEMs demand quality systems for processes as well as products. How to implement it, and its limitations.

The PCB industry has a large variety of processes. For the mechanical processes (e.g., drilling, pressing) the use of statistical methods for monitoring and qualifying these processes is standard. Wet chemical processes are more complex, however, and SPC is limited to isolated cases. Yet many process steps are involved, and the potential fault-inducing parameters just as varied.

Customer requirements demand many fabricators apply SPC for all processes. One reason: Many companies base their quality management system on DIN ISO 9000, which requires the use of statistical procedures like subgroup systems, quality control charting, capability studies, and so on.

It is increasingly observed that customer quality control requirements are not limited to the quality of the final product, but also include the integrity of the production process itself. In this respect, the use of SPC for process qualification is required in several industry and company guidelines (especially for suppliers to the automotive industry).

Until recently there was no national or international standard regulating the introduction of statistical methods to the different production processes. Even the DIN ISO 9000 standard does not give recommendations on how to apply SPC to the different processes. This forces many companies to develop their own statistical procedures, which presupposes the knowledge of the statistical tools of SPC, as well as their applicability and limitations.

The main difference between SPC and the widely known statistical quality control (SQC) is shown in Figure 1.

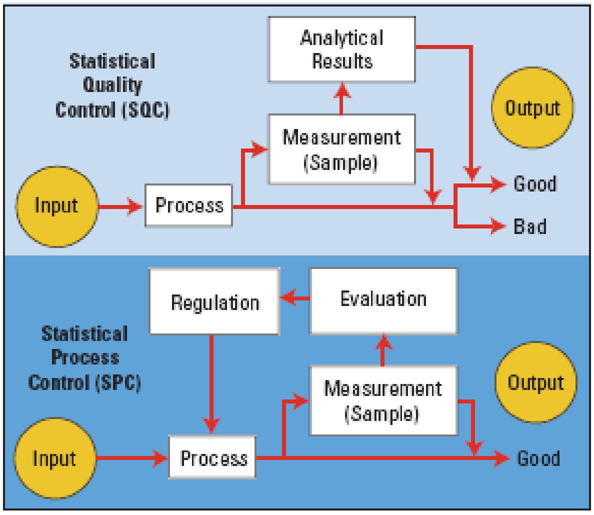


FIGURE 1. The principles of SPC and SQC. The main difference is that SPC reveals deviations before the parameter goes out of spec.

For SQC, a sample is taken and measured. Depending upon the measured value, a decision is made as to whether the product parameter is within the specification or not.

For SPC it is also necessary to measure samples, but the obtained result, is evaluated by statistical means (e.g., control charts). This statistical evaluation makes it possible to gain information about the process. The most important difference versus SQC is that, with SPC, deviations are detected before the quality parameter is out of specification.

Figure 2 shows the different control loops of SPC in detail.[1] There are basically two control loops: an inner control loop close to the machine ("operator loop"), and an outer control loop which includes all issues that need to be discussed by management ("management loop"), e.g., changing of specification limits or equipment changes. Within the inner control loop the operator regulates the process manually or technically supported by quality control charts. A short-term process improvement is obtained. Based on the statistical assessment of process data, the outer control loop strives for long-term improvement; process capability studies and long-term studies are used here.

Many advantages can arise out of the correct use of SPC:

- A better and more objective judgment of the process.
- Deviations that could lead to failures are detected at an early stage and the distinction between systematic and random errors is possible.
- Introduction of continuous process improvement.

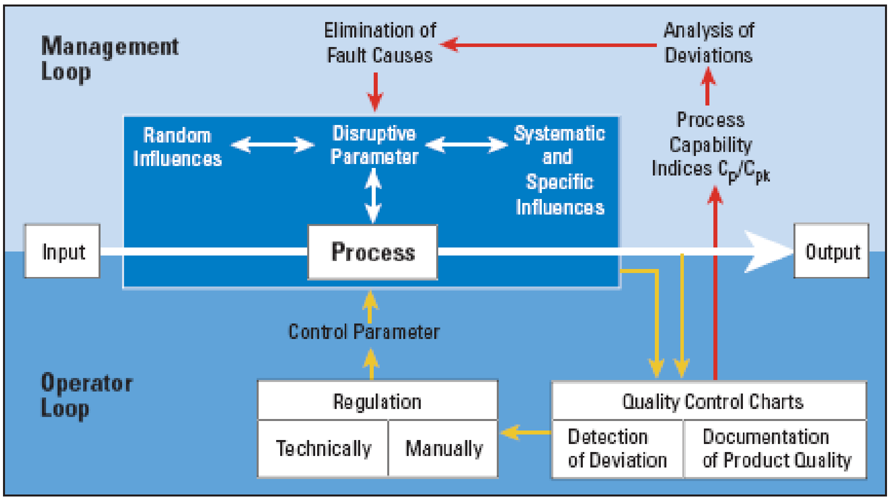


FIGURE 2. The control loops of SPC include an inner ("operator loop") and outer ("management loop").

The main tools of SPC are quality control charting and process capability studies. (Many other statistical tools like Pareto analysis, Ishikawa diagrams, and so on are often linked with SPC, but are not discussed here.) Control charting is a commonly used and very effective statistical tool for visualizing and monitoring processes with regard to their spread and location. To be able to estimate location and spread of process parameters during production, subgroup samples are taken regularly throughout the production and their characteristic values for spread and location (mostly standard deviation and mean value) are calculated. Afterward, these characteristic values are plotted in the control chart versus sample number or time and compared with so-called control limits. In this way, these charts represent the chronological development of a process.

Figure 3 shows the typical design of a control chart. The chart contains a centerline that represents the average value of the quality characteristic and two horizontal lines, the upper and the lower control limits. The control limits are chosen in such a way that if the process is in control, nearly all of the sample points will fall between them. Points outside the control limits indicate that the process is out of control and corrective action is required. Since the control limits are situated within the tolerance limits, deviations are detected before the sample parameter is out of specification.

Normally two control charts need to be maintained: one for the process spread and one for the process locations.

Depending on the process behavior there are two basically different kinds of quality control charts: target and tolerance orientated control charts.

The **target orientated control chart** (e.g., Shewart control chart) is used for uniform processes without systematic influences.

Its aim is the detection and elimination of systematic influences.

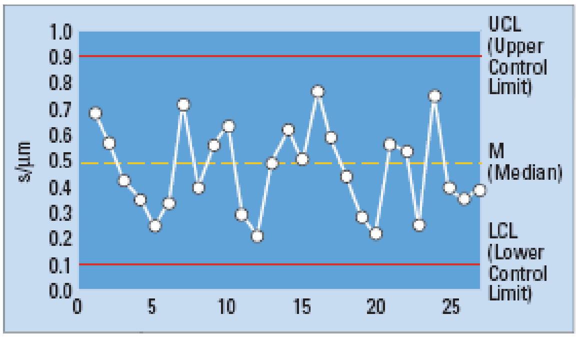


FIGURE 3. In a quality control chart, the centerline represents the average value of the quality characteristic, while the horizontal lines show the upper and lower control limits.
If the process is in control, nearly all sample points will fall between them.

The calculation of the control limits is independent of tolerance limits. The control limits are calculated from the process data and represent the random spread of the process.
Points outside the control limits indicate systematic influences.
The **tolerance orientated control chart** (e.g., acceptance chart) is used for non-uniform and trend processes. As long as all points fall within the control limits, the tolerance orientated chart guarantees that, at the time of sampling, the process is located with sufficient distance to the tolerance limits.
The calculation of the control limits is dependent on the tolerance limits.
Maintaining the appropriate control chart makes it possible to identify significant changes in process spread or location and to gain significant information regarding the process behavior.

Process Capability Studies

For the general understanding of process capability it is important to distinguish between process control and process capability:
Process control is a condition of a process from which all special causes of variation have been eliminated and only common and known causes remain.[2] It predicts how the process will behave.
Process capability is the real performance of the process compared to the specification.[3] The process capability is described by the process capability indices, C_p/C_{pk}.
Figure 4 shows different kinds of processes in order to help visualize the difference between process control and capability.[4]

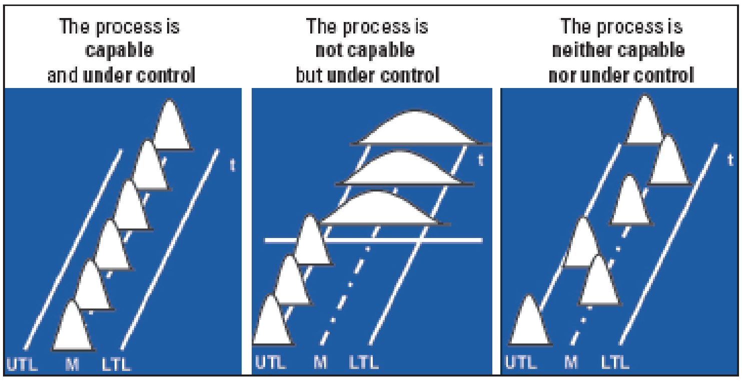


FIGURE 4. Types of processes used to help visualize the difference between process control and process capability.

The C_p index is calculated by dividing the tolerance by the measured process spread. The process spread is defined as the process interval which contains 99.73% of the data. In the case of normal distribution, this interval corresponds to six times the standard deviation (Figure 5). Very often the process isn’t centered, but nearer to one of the tolerance limits. In this case, the C_{pk} index (critical process capability index) needs to be calculated.

The C_{pk} index also considers the position of the mean value in relation to the limiting values of the specification. Figure 6 illustrates the different meanings of the C_p and C_{pk} values.
The minimum requirement for process capability is 1.33.
In other words, the process spread has to be below 75% of the tolerance used. Capability studies are a widely used statistical tool and capability indices are calculated for all kinds of processes. However, in order to correctly apply capability studies, special requirements have to be met. Capability studies are applicable only for uniform processes; trend processes or processes with any kind of systematic influence cannot be assessed by capability indices. The simple formulas shown in Figure 5 can be used only if the measured data follow a normal distribution. For other distributions the formulas have to be adapted. Moreover, the capability studies should only be used in connection with quality control charts as the calculation of capability indices alone does not give any information regarding the state of the process.

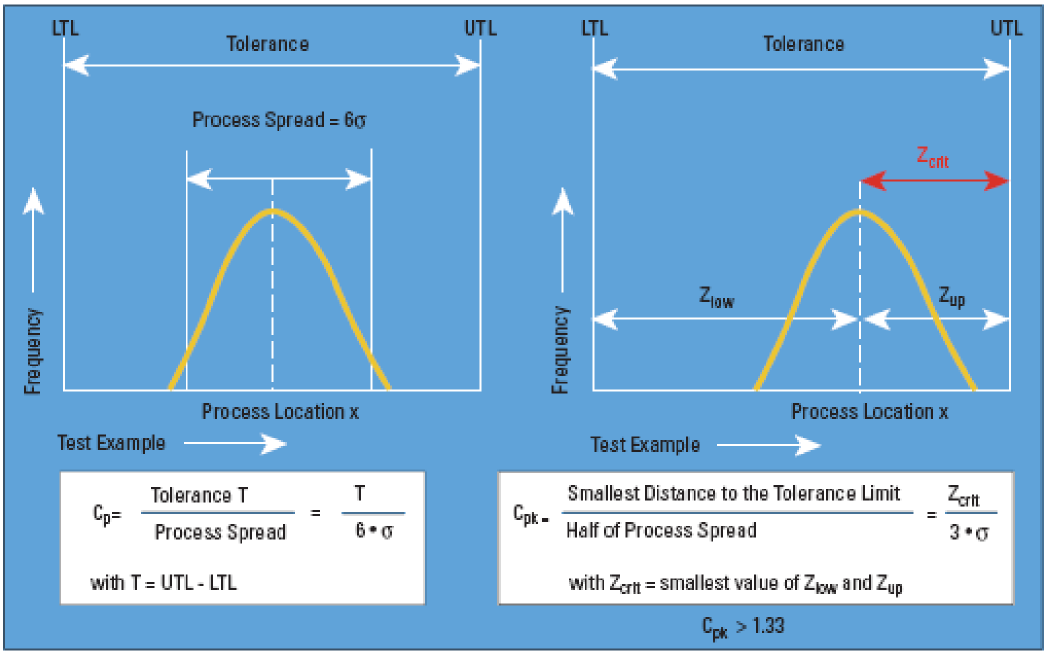
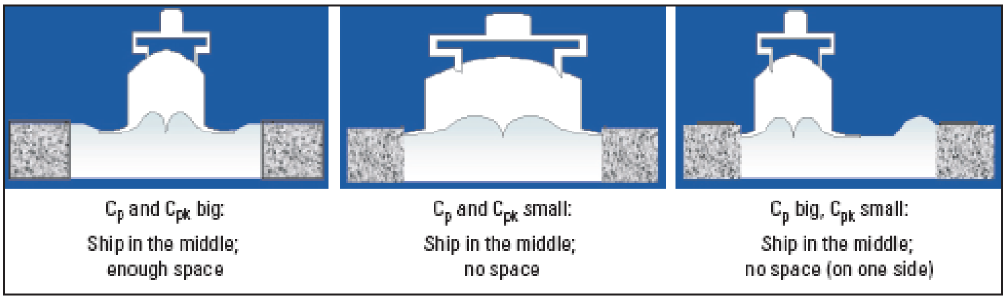


FIGURE 5. The calculation of the C_p/C_{pk} indices. Note that trend processes or processes with any kind of systematic influence cannot be assessed by these indices.


C_p and C_{pk} big:
Ship in the middle;
enough space

C_p and C_{pk} small:
Ship in the middle;
no space

C_p big, C_{pk} small:
Ship in the middle;
no space (on one side)

FIGURE 6. The different meanings of the C_p and the C_{pk} indices.

Implementing SPC

The implementation of SPC for production processes can be subdivided into five necessary steps (Figure 7). The first step is always to decide which process should be controlled by SPC and which test characteristics should be used to **evaluate the process** by statistical means. It is important to decide which parameters are critical for the process and which parameters can be measured, recorded, and assessed with reasonable effort.

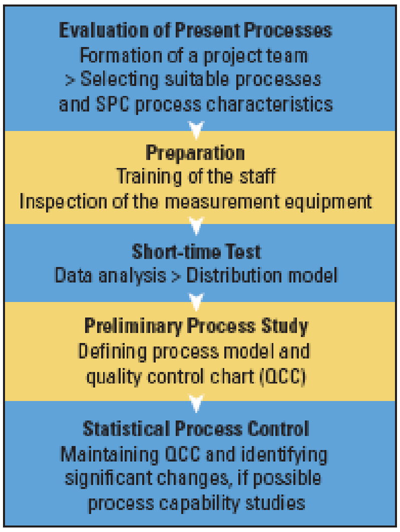


FIGURE 7. Implementing SPC is a fivestep process and involves management and production staff.

At the same time, a project team should be formed, consisting of members from the management team and the production team.

The next step is the **preparation** phase. It is very important to prepare and train the technical staff adequately. (Very often, people’s reservations, which often even border on aversion to anything connected with statistics, have to be overcome.) Mechanical preparation is performed by inspecting the measurement equipment. Similar to the process capability, it is possible to calculate so-called measurement system capability indices. To some degree, all measurement systems have some measurement errors or uncertainties. But if the measuring error is too big compared to the process spread, the measured results will be highly inaccurate and the process spread will appear larger than it really is. The test equipment capability determines the size of the measurement error and its resulting influence on the process spread.

The following step is a process data analysis using a **short-term test**. A short-term test implies that at least 50 parts (one big sample) produced by the equipment are evaluated.

The goal of the short-term test is to obtain a suitable mathematical model to describe the current process. The better this mathematical distribution model, the more accurate all the statistical results and the more valuable all the information obtained. On the basis of the chosen model, estimates can be given for the process spread and the process location, e.g., the standard deviation s and the mean value x.

A well-known distribution model with many favorable mathematical qualities is the normal distribution. The normal distribution is the basis for many statistical tools.

To assess how well the model matches reality, graphical methods such as the normal probability paper or the histogram as well as mathematical methods like regression tests can be used.

A so-called **preliminary process study** is the next step.

During a preliminary process study a minimum of 20 subgroups (with typically three to five samples per subgroup) should be taken under normal working conditions. The aim of this study is to find a suitable process model. The appropriate distribution model has already been determined after the short-term test. Now a process model which describes the process behavior as a function of time should be defined.

Three basic process models shown in Figure 8 can be used to approximate nearly all real-life processes. On the basis of the chosen process and distribution model, a suitable quality control chart is defined. The final phase – **SPC** – includes the maintaining of the quality control charts and, if possible, the process qualification through the process capability indices C_p/C_{pk}.

With the help of the quality control charts significant changes in process spread and location can be identified. For introducing continuous process improvement all actions and observations are recorded.

The chosen distribution and process model should be verified regularly.

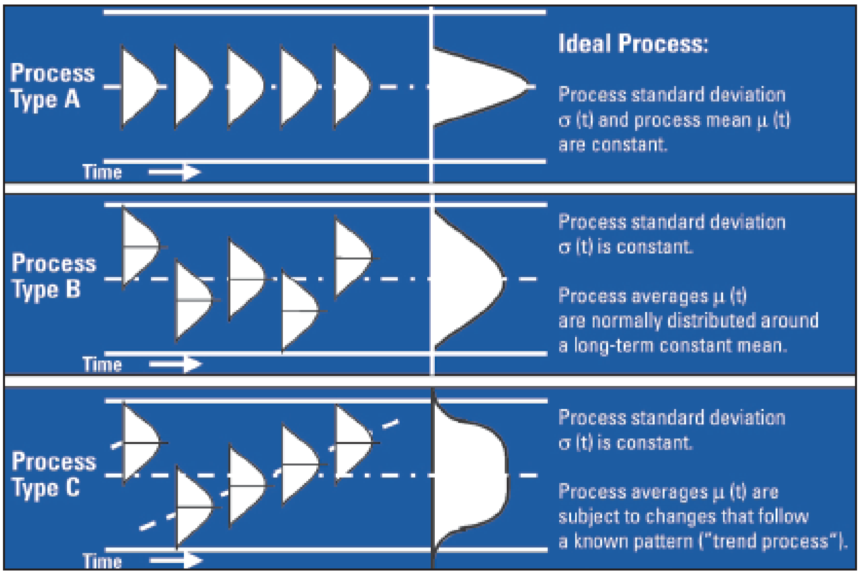


FIGURE 8. The three basic process models. These can be used to approximate almost every actual process.

Special Issues for Wet Processes

If SPC is to be applied for wet chemical processes of the PCB industry, special issues have to be taken into consideration. For mechanical production, SPC is already a standard. Wet chemical processes, however, are different. The existing wet chemical processes are very complex, and include numerous different process steps with just as many influencing parameters. Additionally, there are a large variety of materials to be processed.

Due to the complexity of these processes, there is often a lack of models describing the relation between process characteristics (e.g., film thickness) and process parameters (e.g., air agitation). Moreover, the boards are often treated in baskets or on racks as batch processes. These batch processes show various systematic influences that have to be taken into consideration.

For example, in electroless copper plating, there is a systematic influence on the distribution of the copper thickness between different boards in one basket due to shielding effects.

For wet processes there are two main potential applications: concentrations of components of quality-relevant active baths, and selected surface characteristics.

Quality-relevant active baths. It is recommended, in any case, to monitor the concentrations of selected active baths with the help of quality control charts. Only tolerance-orientated charts should be used here, because there are systematic influences on the chemicals of active baths. The chemicals are added, consumed, and dragged out over time. There is usually a typical sawtooth effect on concentrations over time. The calculation of process capability indices does not make sense in this case, because trend processes are not qualified by process capability studies.

Selected surface characteristics. Quality relevant characteristics of the surface (e.g., layer thickness, roughness, peel strength, etc.) are suitable parameters for SPC. The layer thickness is often used for monitoring processes by statistical means.

Depending on the type of process, tolerance- or target-orientated control charts can be used. Systematic physical influences on the thickness distribution can be minimized by the exact fixing of the measurement point. The variety of different materials can be grouped into sets of similar materials, which are then controlled in one control chart. After choosing the appropriate distribution and process model and after establishing process control, it is also possible to calculate process capability indices.

Apart from the increasing quality requirements of customers and their request for statistical qualification methods, SPC offers various potential benefits that make its implementation worthwhile.

Due to the complexity of the PCB processes and their various influencing parameters, the limitations of the statistical tools should always be taken into consideration.

There are special requirements like the basic knowledge of the relationship between process parameters and process results, sufficiently trained staff and sufficient data, which are a necessity for applying SPC. Statistical tools like process capability studies or target orientated quality control charts cannot be used for each process; in some cases it is better not to apply them.

Many companies get so busy calculating process capability indices for their processes that they lose sight of the main goal of SPC, which is the identification of significant changes in the process and the implementation of continuous process improvements. Capability studies are a useful statistical tool, but numbers alone will not improve the process. The process has always to be seen as a whole; never lose sight of the goal of process improvement.

REFERENCES

1. Harald Lampey, “SPC und kontinuierliche Prozesse – ein Widerspruch?“ *Qualität und Zuverlässigkeit* (QZ) 40, [January] 1995.
2. Preliminary Process Capability Study Guideline, Ford, Köln 1997.
3. Ibid.
4. E. Dietrich and A. Schulze, “Guidelines for the Evaluation of Measurement Systems and Processes, Acceptance of Production Facilities,” Carl Hanser Verlag, 1998.

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