A Journey to Process Improvement

SPC charted the route.

-James P. Bryan

In October 1993 I met with representatives of Automata Inc. (Sterling, VA) to discuss statistical process control (SPC) as a core discipline approach in solving manufacturing problems. The methodology, I explained, would begin with the company's engineering department setting the upper and lower control limits of its processes and the operators collecting and plotting SPC data.

Each process project would have three well-defined elements: discovery of variability; DOES (design of experiments) to define boundary conditions; and redefinition of control limits to produce the most complex attribute with high, sustainable yields. Because many of the elements in a set of processes would interact, several DOES might be needed to determine the limits for each process element.

Prelamination Cleaning

Automata's prelamination cleaning line consists of reverse-current electroclean, double water rinse, two-station microetch, double water rinse, and drying. Although its mechanics were functioning flawlessly, the line was producing panels with a very nonuniform appearance top-to-bottom and mottled leading and trailing edges. The pink cast of the panels was more pronounced in the morning hours of operation. The electrocleaning chemistry, supplied by the equipment manufacturer, was being used at full strength and changed out on a time-related basis.

Laboratory records provided a clue to the problem. Although the engineering specification for microetch was 75 to 85 µin., charts of the results of microetch samples for the two previous weeks showed a clear pattern of high readings (up to 114 pin.) in the mornings and low readings (down to 38 Kin.) in the late afternoons. In an effort to stabilize the microetch, a control chart was established with 75 µin. as the lower precontrol limit and 72 µin. as the lower control limit; and with 85 µin. as the upper precontrol limit and 88 µin. as the upper control limit. Any reading within the precontrol limits would require no action, nor would any single reading between the precontrol limit and the control limit. However, two consecutive readings between the precontrol and control limits would require immediate action to bring the process back into control, as would any single reading outside the control limits. The frequency of the system's sampling and its analysis would continue to be done at a rate of four times per day.

After two weeks of operation, the Cpk for the precleaning process showed a very high variability level of 0.07. Maintaining the same control limits, sampling frequency was increased to once each hour to monitor the effects of process changes. The manufacturer of the cleaning line installed a closed-cell PVA roller immediately following the final rinse to partially dry the panels prior to air drying.

Combining better drying with an adjustment of the pH of the microetch to <0.50 produced panels with a uniform pink coloration and no mottling. When engineering assembled and installed a new automatic controller to make microetch additions based on copper concentration, the Cpk rose to >0.50. The increased level of control was welcome but still deficient, and additional work is needed to maintain a Cpk of >1.33.

Exposure

After the application of dry-film primary imaging material with a high-volume cut-sheet laminator, panels were exposed in noncollimated light machines. In the innerlayer operation, two 5-kW units exposed the bulk of

the panels and two 3-kW units handled overflow, which was restricted to P/G or >6/6-mil products. The exposure units were evaluated in terms of both the physical condition (reflectors, lamps, photoreceptors, and frames) and light intensity and profile across the frames. The profile revealed that the 5-kW units had exposure variations of 52 and 94%, and the variations of the 3-kW units were 12 and 22%. Factory specifications allow 20%.

Maintenance consisted of operators cleaning the machines' exteriors daily and their reflectors weekly, with preventive maintenance being performed on a monthly basis. Any burned-out lamp was replaced, while its mate continued to operate without being tested for diminished output. Our inspection indicated that several reflectors needed to be replaced due to corrosion, and that many of the photoreceptors would not calibrate and also needed replacement.

All four units were baselined by replacing all discrepant parts and calibrating the photoreceptors to the integrators. Exposure variability immediately dropped to a maximum of 18%. The operators reported that the units were easier to set up at the start of a shift, and with no additional process changes, Automata realized a small, incremental yield increase.

Developing

The DES line operated with no formal control mechanisms. Developer chemistry was delivered to the system from a 3,000-gal./day tank at a nominal concentration of 10 g/1 and a pH of >11, The pH meter that operated the solenoid valve controlling fresh developer flow would not stay in calibration for more than several hours, and because of its age and the harsh environment, the valve often failed to open. Resultant rapid pH swings caused the operators to make constant conveyor speed adjustments to maintain the desired resist breakpoint. The Cpk of the process was <0.30.

After the line's potassium carbonate developing solution was replaced with a proprietary developer and the vendor's controller installed for additions, process stability quickly rose to a point where operators no longer had to keep changing the line speed. Within a month, the respective Cpks for pH and total carbonate were 2.20 and 1.20, and as a subsidiary benefit, the waste stream from this process element was reduced by 70%. After the new controller's hysteresis had been fine-tuned (from 0.05 to 0.01) and the developer feed rate adjusted (from 5 to 3 gpm) for several months, the Cpks for pH and carbonate concentration had risen to 6.69 and 1.50. The effectiveness of these improvements led Automata to install similar controllers for outer-layer and LPI developing.

Etching

Although the proprietary etching material was producing good results, the shop's pH and Baumé instruments were causing some problems. Only the Baumé instrument had a control function, that of adding fresh etchant. Startup was frequently complicated when pH and Baumé conditions were so low that operators had to run blank copper panels through the machine until the Baumé level rose sufficiently to add enough etchant to raise the pH.

Two changes were made to bring the etching element into better control. A more accurate Baumé controller was installed, and the existing pH meter was piped into the etcher's vent to remove excess ammonia at elevated pH conditions. Although these improvements were not as effective as converting to anhydrous ammonia for pH control, the stability of the existing process was greatly improved, as the Cpks for etch pH increased from 0.32 to 1.44 and for specific gravity from 0.45 to 3.37.

stability

By mid-December the discovery of variability phase and equipment baselining was essentially complete. Using the dry-film manufacturer's recommendations for its material, we began a series of DOES to define the optimum boundary conditions for using that supplier's product in producing very complex 5/5-mil circuitry. Due to the limited number of steps in the innerlayer process, nothing larger than an L4 DOE array was needed, and we could usually limit the number of sample panels to 40 or fewer. To limit bias in process decisions, it was agreed that AOI would be the "eyes" of the process, and three people would independently review a defective product to assign a cause for the defect. At the end of each run, the group of three would compare notes in reviewing the process and considering the defects.

After five DOES and capping runs to ensure the process results were consistent within a given set of process conditions, I wrote the following letter in January to the area production manager and process engineer:

During a long-term yield improvement program like the one we embarked on in the innerlayer area, we often become so involved in day-to-day details that we forget where we started. Below is a comparison of the yields from our "base" period (the beginning of November) with the most recent yield report.

Part Number	Base Yield (%)	Current Yield (%)
1261.23	72	100
1460.23	96	100
1460.67	99	100
1460.1011	92	91
1462,23	88	95
1462.67	98	100
1462.1011	89	95
1525.23	93	97
1551.23	91	95
1551.67	76	83
1558.23	76	96
1573.23	60	99
1591.23	61	100
1591.67	85	98
1261.45	49	99
1460.45	83	99
1460.89	89	96
1462.45	85	90
1462.89	92	96
1523.45	87	95
1551.45	87	95
1551.89	95	97
1558.45	80	94
1573.45	59	100
1591.45	68	100
1591.89	71	100

By using SPC to define and control process variability and DOES to define boundary conditions, Automata's overall process yields were increased from the mid-80% range to over 97% in 13 weeks.

I urge you to have a meeting with all employees in these process areas and share the good news *with them. They need to understand that their efforts are paying big dividends; they also need to understand that their journey has just begun, and that eventually their processes will work "just like science."*

Conclusion

SPC as a process tool not only worked, but worked so well that Automata expanded its use from the original seven charts in innerlayer to 78 in the wet processing area. More charts are being implemented weekly. Each month Automata's quality group summarizes its data and publishes salient statistics from the preceding three months, informing everyone of the state of process health.

SPC is not an expensive, complex, high-tech process that requires new layers of overhead for implementation, It is a simple, straightforward methodology for managing the manufacturing process. Most people need little more than one day of training to grasp its essential concepts, and all SPC data can be calculated with an inexpensive hand-held calculator. SPC charts and Cpk data derived from such information provide an effective route to real process improvement- FAB

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