STATISTICAL PROCESS CONTROL FOR REEL-TO-REEL PLATING: THICKNESS CONTROL ON SHORT RUNS

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ABSTRACT

Operators of reel-to-reel plating lines must closely control plating thickness. Too much plating, and the plater loses money. Too little plating, the customer rejects the job.

While standard SPC techniques help control plating thickness in many applications, reel-to-reel plating brings special problems. For job-shop platers, this problem is particularly acute. With fast line speeds and routinely short coils, operators normally splice and replace reels every ten to thirty minutes.

How can platers use SPC to insure that they meet plating thickness specifications? How can they keep up with the constantly changing reels? What shortcuts would allow rapid charting, but yet maintain adequate control?

This paper will look at the use of Pre-Control, Narrow Limit Gauging, and central target control of the plating thickness. The paper will also discuss using SPC to control the inputs to the process, not just the output. Standard SPC charts help control the inputs, while the modified techniques control the outputs.

DESCRIPTION OF THE PROBLEM

Reel-to-reel plating provides a convenient method for plating continuous strips of substrate. The substrates can range from steel strip, plated with zinc, to electronic lead frames, plated with gold. The substrate spools off one reel, is guided through the cleaning and plating solutions by rollers, then collected on a take up reel. This allows plating parts too small, or too long, for conventional rack plating.

Frequently the plater must closely control the plating thickness. Particularly with the precious metals, the plater needs to control the plating thickness closely. If he fails to plate the required thickness, the customer may reject the lot. If the plater plates an excess of the metal on the substrate, he loses money.

Statistical Process Control offers many advantages to control plating thickness. It acknowledges the reality of the inherent process variation, measurement variation, and unknown sources of variation. Given these variations, the operator must take care to not overcontrol the process, making corrections when not needed. By use of control limits, with or without added decision rules, you can separate a real change in the process average from the normal variation.

Reel-to-reel plating presents special challenges in the application of SPC for plating thickness control. For those in job shop plating, the challenges become particularly acute. With fast line speeds and routinely short coils, operators of reel-to-reel plating lines normally spice and replace reels every ten to thirty minutes. Added to this tight schedule, the operator may also have responsibility for monitoring line processes, maintaining the machinery, and maintaining the bath chemistry. Is it any wonder that these operators protest when on top of all this, we ask them to keep SPC charts?

Where can operators find the time to calculate control limits for each new coil? How can they even find the time to calculate the average and range for each sample? When will they fit in the time to chart all the data onto the control chart? More importantly, when will they find the time to look at the chart, and decide what they will do to the process?

THE SOLUTIONS DESCRIBED

This paper presents several suggested solutions to this real world problem. We do not present these solutions to determine the one 'best' solution. The solutions are not mutually exclusive, and you should not see any one of them as the best in all situations. Any one of these solutions may work in a given plant, or it may take a combination of several of the solutions to solve the problem.

The solutions presented in this paper are:

1. Central Target Control Charts
2. Pre - Control Charts
3. Graphical Medians -- Range Charts
4. Narrow Limit Gauging
5. Computer Based Control Charting
6. Fully Automated Data Collection and Analysis
7. Controlling the Inputs

1. CENTRAL TARGET CONTROL CHARTS

Central Target Control (CTC) charts offer a great reduction in the calculations needed for standard control charts. This reduction comes at the expense of sensitivity in detecting changes. If the chart meets the conditions and assumptions underlying it, then it remains more than sensitive for normal use.[1]

The name 'Central Target' derives from trying to keep the plating thickness centered within the specified tolerance. In use, you do not calculate control limits. Instead you use the plating thickness tolerance. This simplifies the task of the operator, as they do not calculate new control limits for each reel. As the operator places a new reel on the plating machine, the only information needed to start the control chart for that reel is the plating thickness tolerance.

You cannot control every process with such a simple control chart. In particular, processes controllable with this chart must have small amounts of process variation compared to the tolerance range. If the total process spread occupies 75 % of the tolerance, or less, you can control the process with a Central Target Control chart.

Do not take this requirement lightly. Rarely will a process not presently under SPC meet this requirement. This solution works best on existing lines, with a large amount of data available to determine the amount of process spread. Such a study will also allow a determination of any plating jobs that may not follow the 'normal' process spread. You can then treat these jobs separately from the other jobs.

To use the Central Target method, the operator takes the plating thickness tolerance for the reel and divides it into four or eight sections. The divisor depends on the estimated percentage of the tolerance occupied by the normal process variation. If the process variation fills 75 per cent of the tolerance, divide the tolerance into eight sections. If the process variation fills 50 per cent of the tolerance, divide the tolerance into four sections.

In either case, any point in the outermost zone, on either side of the average, shows the process drifting out of control. The operator must take corrective action to prevent production of defective plating. It is very important that the plating thickness average fall near the nominal of the tolerance. A shift from the nominal value weakens the detectability on the side away from the move. Figure 1 shows two examples of Central Target Control Charts.

It is interesting to point out that a plating shop has used this technique for many years, with great success. Only within the last ten to fifteen years has Dr. Taguchi demonstrated the importance, and great value, of producing all parts near the nominal, instead of at the extremes.

2. PRE - CONTROL CHARTS

Frank Satterthwaite developed Pre-Control charts while working for the consulting firm of Rath and Strong. Pre-Control offers an alternative to standard Shewhart type control charts. The consultant Dorian Shanin remains one of the leading proponents of Pre-Control[1], along with his disciple, Keki Bhote[3]. While similar in some ways to Central Target charts, Pre-Control offers several refinements, that improve the utility of the technique.

Pre-Control uses four basic rules for chart formation and operation.

Step one:

"Divide the specification width by 4. The two innermost quarters form the "green zone." The boundary between this central area and the outer two quarters form the "PC Control" lines. These outer two quarters are the "yellow zone." The area outside the specification limits is the "red zone."

Step Two:

To determine a preliminary estimate of the present process capability, take five consecutive parts from the process output. If five consecutive parts fall within the green zone, before two consecutive parts fall within the yellow zone, consider the process in a state of control.

If even one part falls outside the green zone from the first five, the process is not in control. You must take corrective action to improve the process before starting production.

Step Three:

Once you start production, take two consecutive samples from the process output on some periodic basis.

1. If both fall within the green zone, continue production without change.

2. If one part falls in the green zone, with the other in the yellow zone, consider the process in control, and continue production.

3. If both parts fall within the yellow zones, two possible actions exist. If both parts fall in the same yellow zone, you must adjust the process. If the parts are in opposite yellow zones, the process is out of control, and production must stop. Do not resume production until you discover the cause of the excess variation, and correct it.

4. If even one part from the sample falls in the red zone, all production must stop. This means the part is defective. You must find the cause and take corrective action.

Anytime you stop production as a result of violating rules 3 or 4, return to Step Two above, and insure the process has returned to a state of control by producing five consecutive parts within the green zone.

Step Four:

Calculate the frequency for taking the two consecutive samples by dividing the average time between stopping production by six. If the process runs for six days without breaking rule 3 or 4, then take the two samples once a day. For example, a process that averages 60 minutes between stoppages would require samples every 10 minutes.

While you do not have to plot the data for Pre-Control to work, I always advise that you do not skip this step. Plotting the data will often reveal subtle patterns or clusters in the data, that reduce the sensitivity of the test. The plotting takes so little time, the potential benefits far outweigh the time spent.

3. GRAPHICAL MEDIANS -- RANGE CHARTS[4]

Control charts using the sample median, $\tilde{X}$, provide a reasonable alternative to $\overline{X}$ charts for measured (variables) data. Median charts tell us the process center location and they answer the same questions as a chart for averages.

lotting medians offers several advantages to plotting averages.

1) Median charts are simple to use. After calculating the centerline and control limits, you do not need any other calculations to plot the sample results.

2) Operators need only plot individual readings on a graph so it is usually easier to get a SPC control chart program accepted in the shop.

3) When using charts for medians, you plot the individual measurements directly on the chart, so it may not need to write down the actual numbers.

4) Since this chart requires no calculations, once the control limits are set, the chart provides a fast, accurate tool for process control.

For a given sample size, medians charts lack the sensitivity to process hanges as charts for averages. In most situations this is of minor consequence onsidering how easy the charts are to use.

The R chart for ranges is the same as that used in $\overline{X}$-R charts. You should ot use the median chart without the R chart. A R chart is necessary to detect atterns caused by variations in the process spread.

Making the Chart for Medians and Ranges, $\tilde{X}$-R Charts

Set up the chart as if you were making an $\overline{X}$-R chart. Gather the measurements on 20 or more samples of size n in production order. During the nitial performance study period write down the data, even if you do not plan o do so once the chart enters routine use.

Plot the individual readings on the upper graph. Find the median value and circle it. Small sample sizes consisting of an odd number of measurements (n=3, 5, and 7) are ideal for median charts. Connect the sample medians with straight lines to emphasize the pattern profile. Again, during the study period, write down he median values.

You can obtain range values by subtracting the lowest reading from the highest reading in the sample. You could also count the increments between the extreme values on the plot. A third method transfers the interval between extreme values to the edge of a piece of paper. You then transfer that distance onto the R chart.

A fourth alternative, and the one I prefer, involves the use of a clear piece of plastic. Calculate the control limits for the range and mark them on the clear piece of plastic. Once you have plotted the sample values on the medians chart, set the piece of plastic over them. If all the points lie within the limits, the range is in control.

1) Obtain the centerline and control limits for the R chart as before.

2) Calculate the centerline for the X chart by averaging the medians.

We symbolize the average of the medians with $\bar{\tilde{X}}$.

3) Use the average range, $\bar{R}$, to calculate distance between the centerline and the limit lines for the median chart. You must use special A5 factors to figure the limits for medians. These factors vary with the sample size n. Tables in books on SPC list these values.

Interpretation of Median and Range Charts, $\tilde{X}$-R

Interpret the $\tilde{X}$-R chart for out-of-control points, unusual patterns, etc., the same as for the $\bar{X}$-R charts.

Remember, if the R chart is out of control, you cannot accurately interpret the $\tilde{X}$ chart. *Do not interpret* the $\tilde{X}$ chart until the R chart has returned to a state of control.

4. NARROW LIMIT GAUGING

If you can measure the plating thickness with some type of a go/no-go gauge, Narrow Limit Gauging (NLG) may offer a time saving alternative to the traditional control charts. In practice the NLG chart bears many similarities to the Pre-Control chart discussed earlier. In essence, Narrow Limit gauging offers the advantages of small sample sizes, and good discrimination, with the speed and simplicity of go/no-go gauging.

As in Pre-Control, you base the NLG control limits on the tolerance range specified for the part. NLG differs from Pre-Control in that any subdivision of the tolerance into smaller zones depends on having go/no-go gauges within the tolerance band. These tighter gauges allow the use of cautionary lines, similar to the yellow zone in Pre-Control.

For more information on Narrow Limit Gauging, see reference 5.

5. COMPUTER BASED CONTROL CHARTING

One solution, used by many, turns all the calculation and charting over to a computer. The operator collects the data, and enters it into a computer. The computer calculates the average and range, and produces an updated graph. In some systems, points out of control generate an error message, with possible items to check listed on the screen, along with corrective actions 6.

6. FULLY AUTOMATED DATA COLLECTION AND ANALYSIS

To reach our goal of maintaining control of the plating thickness, while at the same time not overloading the operator, will likely require some automated data acquisition and control equipment. Operating under the control of a computer, a sensor measures one of the variables, and records the data in a database. To reach full potential, the system should also have the capability of closing the loop, by sending out a signal to turn on an addition pump, or make some other adjustment. The operator should only need to monitor the system occasionally, providing servicing as needed. Some alarm mechanism should be a part of the system, to signal an out-of-control condition.

For many years, reel-to-reel precious metal platers have used continuous on-line X-ray fluorescence (XRF) spectrophotometers to measure the plating thickness on the reel, just as it comes out of the plating tank. The XRF unit can connect with a computer that controls the plating rectifier. If the plating thickness climbs out of control, the XRF can signal the rectifier to reduce the amperage. If the plating thickness falls out of control on the low side, the XRF signals the computer to increase the amperage from the rectifier.

Similar units have slowly made inroads into controlling other plating parameters in real time. .Electronic stress gauges now available are capable of measuring internal deposit stress in real time. The unit can connect, through a computer, to the rectifier, adjusting the current density to maintain the desired stress level. Plating rate monitors can measure the real time plating rate of the solution, while the parts plate. If you locate the monitor plates at the same current density and agitation conditions as the parts, very tight plating ranges can result. Even if you cannot match the exact plating conditions at the probe, a correlation may be possible between the probe and the parts, allowing improved plating rate estimates.

7. CONTROLLING THE INPUTS

Controlling the inputs to the process offers the best overall solution to our problem. We can view processes as computer programs. For a given set of inputs, another set of outputs will result. We readily admit that real world processes seldom reach this ideal, but the basic strategy remains the same. We should strive to identify all the inputs to a given process, measure their effect on the process, and then control the inputs that affect the output.

Each electroplating solution has its own set of inputs, and differing set of functions relating the inputs to the outputs. While the exact set of important inputs varies with bath type, certain fundamental input variables will usually need tight control.

You should control the plating current density, in electroplating solutions closely. Faraday's law states that the amount of metal deposited depends on the amount of current applied, and the time of application. Since we want to control the plating thickness, we need to know the surface area, and the density of the metal. Then, if we control the current density, we can estimate the plating thickness by knowing the time we plated the part.

In controlling the current density, remember that current density contains two parts. The numerator contains the current applied from the rectifier. The denominator contains the area plated. You must control both for lasting success. Often platers forget the denominator, and start to think of long running jobs as so many amps for so many minutes. The problem comes when someone places fewer parts on a rack, thus less area, yet runs for the same amount of time. Only after overplating the parts does the operator remember that he must concern himself with more than just the amps, he must remember the area as well.

An often overlooked control variable for electroplating, except for most chrome platers, is voltage. Electroplating baths form a simple direct current (DC) circuit. DC circuits obey Ohm's law, which states that the voltage drop (E) in the circuit equals the current flow (I) in the circuit times the resistance (R) of the circuit. Expressed mathematically:

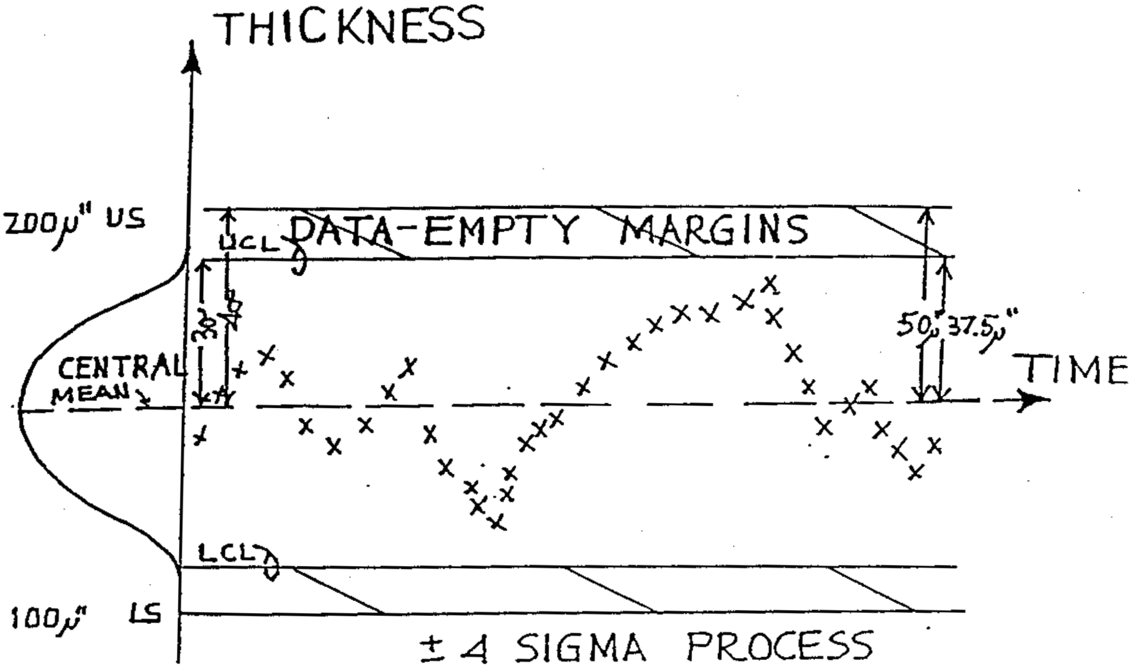
$$E = I R$$

From this scientific principle we can gain more insight into the condition of a plating system. If the voltage needed to maintain a given amount of amps changes, then the resistance of the circuit must have changed. If the voltage drops, the resistance has dropped. If the voltage rises, the resistance has risen. The cause of the change in resistance could come from a change in bath chemistry, or from physical causes, such as a poor connection.

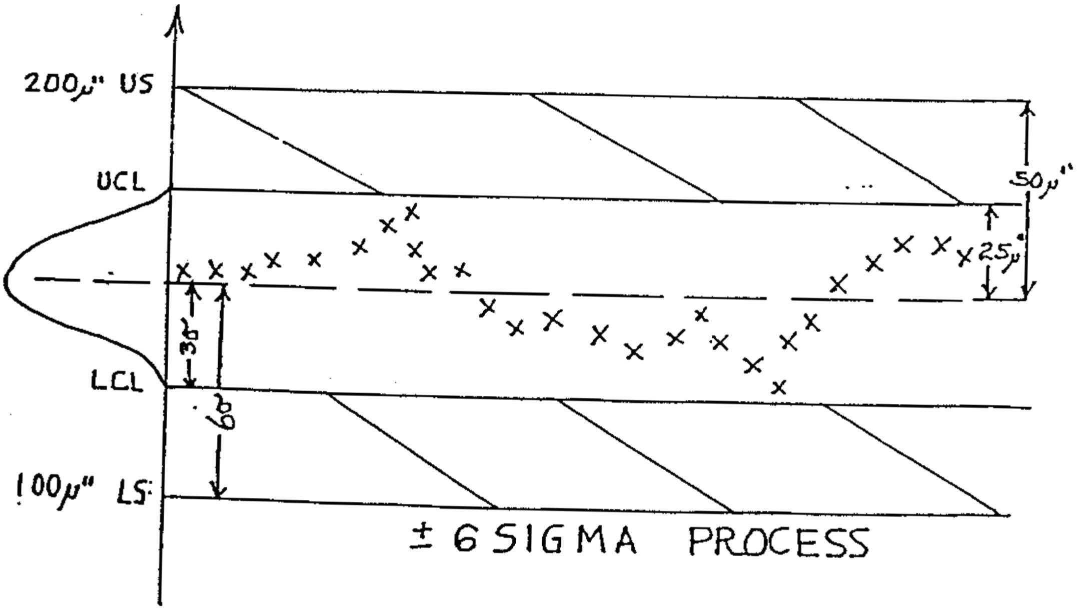
In reel-to-reel plating, the voltage can give an early indication of the need for preventive maintenance. A simple control chart on the voltage required to maintain a set amperage level can provide early warning of problems with passive anodes, poor connections, worn contact brushes, weak bath chemistry, or changing area of the surface plated.

Controlling the inputs ties in well with the sixth solution given above, use of automated data acquisition and control devices. You can easily automatically measure and control the solution temperatures, amperages, voltages, and substrate transfer rate. You can buy continuous, on-line solution chemistry analyzers for many plating solutions.

FIGURE 1



± 4 SIGMA PROCESS



± 6 SIGMA PROCESS

NOTES

1.The authors would like to give credit to an experienced electroplater, Mr. Charles Patterson at Charles D. Snyder & S Inc.. He developed the method outlined here for plating to a central target, in order to cope with the time demands of his organization.

2.Shainin, Dorian. "Better Than Good Old X & R Charts asked b Vendees." ***Transactions of 38th Annual Quality Congress.*** Chicag ASQC Press, Milwaukee,WI. 1984. p 302-307.

3.Bhote, Keki. ***World Class Quality: Using Design of Experiment to Make it Happen.*** AMACOM, New York, NY. 1991 p 171-195.

4.Material in this section first appeared as section 6.3 in ***Introduction to SPC for Surface Finishers.*** American Electroplaters and Surface Finishers Society. Orlando,FL. 199 89-92.

5.Yu, Shawn S., Case, Kenneth E.. "An Updated Look At NLG For Process Control." ***Transactions of the 38th Annual Quality Congress.*** Chicago. ASQC Press, Milwaukee,WI. 1984. p308-314.

6.For a discussion of the potential problems with this approa see: Sugg, David J. "Why Johnny Can't Do SPC." ***Proceedings of 79th AESF Annual Technical Conference- Session A, Quality and Statistical Methods.*** Atlanta: American Electroplaters and Sur Finishers Society, Orlando, FL. 1991.

July 25, 1992

Mr. J. Howard Schumaker, Jr.
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Mr. J. Howard Schumaker Jr.

As a representative for the Waste Reduction Resource Center and an AESF member, I attended the SURF/FIN '92 technical conference in Atlanta on June 22-25. The conference was excellent and the proceedings are a major source of up-to-date information.

I've attached a copy of the WRRC operations. As you can see, we supply technical assistance and copies of technical articles on a no charge basis. The WRRC is the Clearinghouse and Tech Assist group for Region IV EPA.

Two copies(two volumes each) of the International Technical Conference Proceedings June 22-25, 1992 were purchased to become sources of information for Technology Transfer. One copy is in the EPA Region IV library in Atlanta. The other copy is being used as a reference document at the WRRC in Raleigh, NC. Reference Documents are used by many state offices, Universities, and industry. The WRRC also sends copies of articles on request by the general public.

I request that the WRRC and Region IV EPA Library be allowed to make copies of the papers in The Proceedings of the AESF Annual Technical Conference SURF/FIN 92. This will save us (taxpayer supported) the expense of contacting each author/presenter for copies of their presentations.

respectfully

Vic Young
Staff Engineer
Waste Reduction Resource Center

American Electroplaters and Surface Finishers Society

August 4, 1992

Mr. Victor Young
Waste Reduction Resource Center
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Dear Mr. Young:

This is in response to your letter of July 25th in which you requested that the AESF waive its copyright on the papers and the proceedings of the AESF SUR/FIN® Technical Conference '92.

I believe that we have discussed the waiver of AESF Copyright in previous correspondence. Since you are a member of the AESF, you, no doubt, are well aware that the Society derives its income in order to offer services to its membership and to the general public through the sponsorship of educational programs and the sale of its publications. I am sorry that we are not in a position to permit the Waste Reduction Resource Center to make copies of the papers and the proceedings. These may be obtained at a very nominal cost through your Society Headquarters and it is not necessary to contact the author or presenter for copies of these presentations as the authors have given this right to the Society as per the author form required prior to their presentation of the paper.

I sincerely hope that you understand our position.

Very truly yours,

J. Howard Schumacher, Jr.
Executive Director

JHS/pw

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