

CONTROL CHARTING LABORATORY REFERENCES FOR QUALITY CONTROL

Nicholas Mason
Mike Brown
Fluke Electronics
6920 Seaway Blvd
Everett, WA 98206
425-446-6488

Nicholas.Mason@Fluke.com
Mike.Brown@Fluke.com

ABSTRACT

What would you do if you had to Control Chart 200 laboratory references? Control charts are a graphical means to determine if the current measured value falls within the expected range of values based on the history of the reference. It gives instant feedback to the operator that a measurement may be suspect and indicates if systems are in control. Control charts also allow managers to be notified if a measurement is outside the expected limits and take appropriate corrective action.

Unfortunately control charting is also a lot of work. As a result, we only control chart critical items. Over time our list of critical items was well over 200, and each chart was a separate Excel spreadsheet. While this method worked, it was very time consuming to update and maintain 200+ spreadsheets.

A "Kaizen" was called to analyze the problem and implement a solution. A method to capture and use data directly from our database was developed. This solution eliminates the need to maintain the spreadsheets, and has additional advantages for the calibration of the devices.

The methods used are described here and examples are given such that no custom software is required to implement the solution.

INTRODUCTION

Fluke now manufactures infrared thermometers and imaging devices. These devices remotely measure temperature by measuring the radiance of an object. To calibrate these devices they are aimed at temperature plates of known temperature. The exactness of the correct temperature is not as important as knowing, as closely as possible, the actual temperature of the plate. For example, if a device has a calibration point at 100 C, a plate that is at 103.4 C can be used, and the unit will be adjusted for 103.4 C instead of 100 C.

In order to keep track of the actual temperature of the plates, their values are frequently measured and compared to a Control Chart.

WHAT IS CONTROL CHARTING?

Control Charts are a graphical means for detecting variation from the expected values [3]. The simplest Control Chart consists of a center line (CL) representing the nominal value and upper (UL) and lower (LL) test limits. The measured values from the temperature plates are plotted on the chart to ensure that the plate is in calibration and control. If the data is outside of the test limits, it is time to adjust the plate.

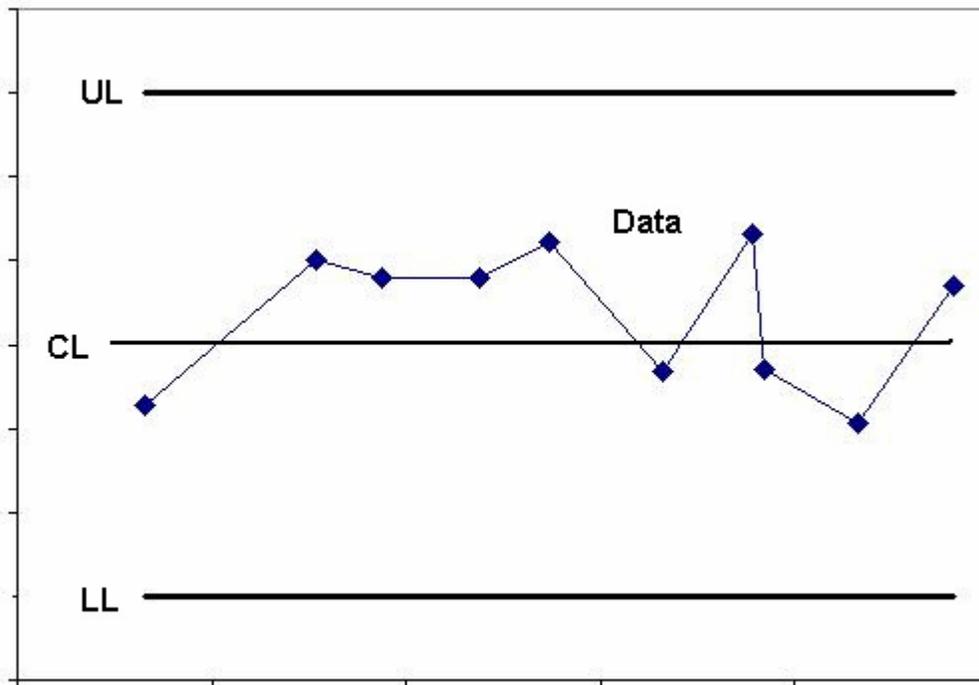


Figure 1 Simple Control Chart

Fluke infrared metrology uses a more complex Control Chart. We need to establish the “official” temperature of the plate. To do this we use a regression line through the data and use that value for a period of time. We also compute the 3 sigma confidence interval around the regression line [1]. We want this variation to be small as the true value could lie anywhere in this region. When the confidence band crosses the limit line due to drift, it is time to adjust the plate. Excel[®] has been successfully used to collect the data and make the Control Charts.

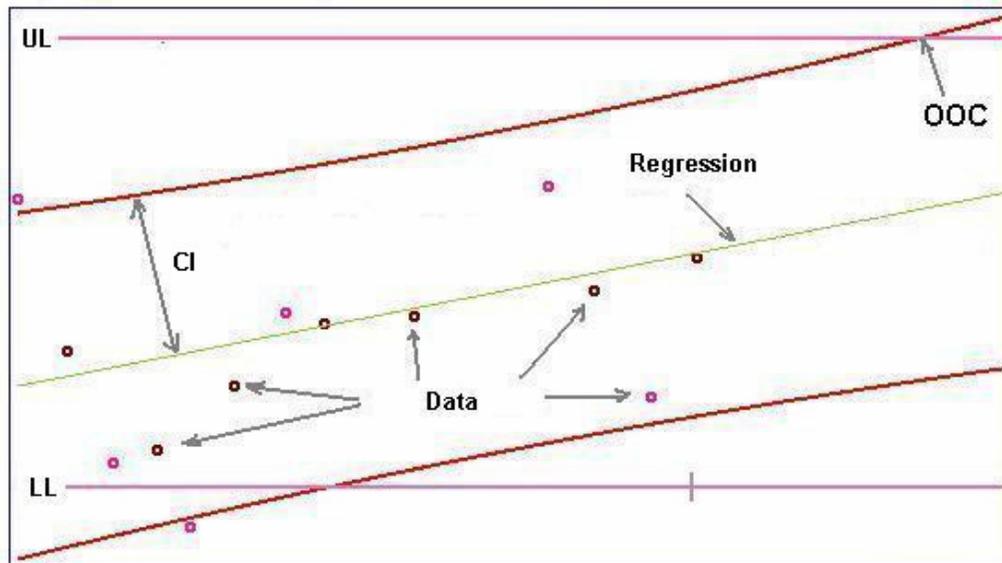


Figure 2 Fluke Control Chart

A Fluke Control Chart is an analysis method used to determine when an instrument parameter will be out-of-confidence and what the estimated value is likely to be. The data points are first plotted against time. Next, a regression line is computed through the data points. The regression is used to compute the estimate at a given time. Based on the scatter of the data, the confidence interval about the regression is computed [1]. The confidence interval (CI) is given by the equation:

$$CI = k \cdot S_{y/x} \sqrt{1 + \frac{1}{n} + \frac{(x - \bar{x})^2}{(n-1)S_x^2}}$$

where \bar{x} is the mean time,

x is the time we are computing the prediction interval for,

n is the number of data points,

S_x is the standard deviation of the x data ,

$S_{y/x}$ is the standard error of the regression and,

k is the coverage factor.

The confidence interval is added and subtracted to the estimated value from the regression equation to give the upper and lower confidence limits of the expected value around the regression line. Finally, the test limit is also plotted on the graph. When the confidence band crosses the test limit, the parameter is Out-of-Confidence (OOC)

SO WHATS THE PROBLEM?

The above method works very well for keeping our temperature plates in control and determining the assigned plate temperature value. However, there were many issues with this approach.

One issue was the sheer number of plates. In early 2008 there were over 200 separate Control Charts and corresponding Excel worksheets to keep track of temperature plates. It was taking one metrologist about 40 hours per month to maintain and analyze Control Charts. Projected growth indicated that we would soon be approaching 400 Control Charts. We could not afford the time commitment to manually maintain the charts, but they are necessary to proper calibration and manufacturing of infrared temperature measuring devices.

Another issue was the approval process for the new "official value". A technician would perform calibration of temperature sources at regular intervals, typically every 30 days, in accordance with a manual paper procedure. The technician entered the measurement results into a spreadsheet at the time of calibration then sent them to a metrologist for review. The metrologist would update an additional spreadsheet for each temperature source with the new data. This included manually updating named ranges, executing macros, and analyzing the data. After review, the metrologist then notified the equipment monitor that the calibration results were acceptable, at which time the equipment monitor manually created a new MET/TRACK[®] calibration record and issued a new calibration label. Finally, the technician would post each temperature source with the new temperature value and affix the calibration label. The technician could now use the plates for manufacturing and calibration. This process typically took about 3 days and in some cases caused delays in manufacturing.

There are several other issues. Each temperature source has the calibrated temperature value for different emissivity settings posted on it. For example 126.1 °C at $\epsilon = 0.95$, 120.1 °C $\epsilon = 0.97$, and 117.3 °C $\epsilon = 1.00$. When a technician calibrates a Unit Under Test (UUT), a MET/CAL procedure prompts them to enter the calibration value for a specified emissivity. This of course is prone to both transcription and transposition errors, as well as the possibility of entering the calibration value of the wrong emissivity. Finally, this approach also does not take into account the drift of the standard, and simply uses a single value throughout the calibration interval.

KAIZEN

Recognizing there were problems in the Control Chart process, the Primary Standards Lab organized a Kaizen to investigate the issue and look into possible solutions. Kaizen is Japanese for "continuous improvement" and is a problem solving process used to eliminate waste and improve processes. In this case we need to improve the process to work with hundreds of plates while spending less time and improve the approval process.

The Kaizen team started with what the ideal process would look like. From there a plan was made to try and reach this ideal process. In the ideal process the data would be gathered automatically and analyzed without any user action. The approval process for a plate would be immediate and the technician would know right away if the plate was fit for use. The problem was broken into two parts: data gathering and data analysis.

GATHERING THE DATA

The first step was to find a way to automatically gather the data. The technician was already creating MET/TRACK records as part of the existing process. So, the first focus was to determine if we could gather the data directly using MET/CAL[®] and create the MET/TRACK records at that time.

MET/CAL is powerful tool for automating calibration and collecting data. However, one of its limitations is the difficulty of extracting data from different calibrations after it is collected. The fundamental MET/CAL paradigm is that the data is going to be collected and then printed on a certificate. While this is often true, it is also useful to correlate data across multiple calibrations. An example will better explain the issue.

Assume we have a simple MET/CAL procedure where we collect data for two test points, 10 V and 100 V DC. In MET/CAL this could look like:

```
1.00 5520 10V 1%
2.00 5520 100V 1%
```

In MET/CAL language we now have two tests, test 1 for 10 V and test 2 for 100 V. The first column is the test number. The next is the name of the source device, followed by the voltage the device will output and the test tolerance that will be used to analyze the results of the test. If the procedure is run multiple times, data for the 100 V test (test 2) can be correlated across multiple calibrations because they will all have the same test number, the first column.

The problem occurs if we change the procedure. The test numbers do not stay with the tests but change when we modify the procedure. If we were to add a 50 V test the procedure could look like:

```
1.00 5520 10V 1%
2.00 5520 50V 1%
3.00 5520 100V 1%
```

If we run this procedure, we would mess up the integrity of our data, as we would now start correlating the 50V results (new test 2) with the older 100V results (old test 2). This is not desirable. We needed a better way to correlate our data.

Other Fluke processes, such as process metrology do not use a test number but use a "step number" [2]. By definition, this step number never changes, even if tests are added or removed. After much thought and discussion in the Kaizen we decided that we could tag our data with a step number by writing a tag value to the test_step2 field in the MET/CAL results table. It was decided that all tags would start with "cc" (for Control Chart) and then be an integer. The value of the integer is not important, just that it never changes for a given logical test. The tag value will allow the correlation of results. Tags are written in the MET/CAL procedure using the MET/CAL function select code (FSC) TSET as shown in the following procedure fragment:

```
9.015 MATH @Tag_Numeric = 11
9.017 MATH Tag_CC = "cc" & @Tag_Numeric
9.018 TSET TSTEP = [V Tag_CC]
9.023 MEMCX 500 V TOL 10kH
```

In step 9.015 the variable Tag_Numeric is set to 11, the step number for this test. The next step prepends the "cc" to the beginning of the step number and stores it into the variable Tag_CC. Next the TSET FSC sets the test_step2 field to the value of the Tag_CC variable. Finally, when the MEMCX evaluation in MET/CAL occurs, the tag will be written along with the data.

When the data for this step is written it will be tagged with the value cc11. Now that the data is being written in an extractable way from the database we can use Excel to analyze it. More about this later.

TECHNICIAN FEEDBACK

We also want to give the technician instantaneous feedback about the the plate measurements.

We can also decrease the time required for the approval process by making acceptable values available to MET/CAL which will give the technician instantaneous feedback about the health of the reference.

If, when the technician measures the value she knows that the value is outside of the Control Chart limits so it is time to adjust the plate. Also, if a reading is outside the the upper or lower confidence

then either the unit has taken a shift, or there was a problem with the measurement. So how can the tech be notified at the time of measurement?

In the Kaizen we came up with the idea of creating a limit file based on the data for the reference. This limit file can then be used in the MET/CAL procedure. Limit files are CSV data files containing information about each step of an asset. Our format of a limit file is:

step number, regress, conf, lowlim, hilim, lotest, hitest, email1, email2, email3

The first value, step number is an arbitrary number assigned by the metrologists to identify the test step. As described later in the paper, it is used to correlate results from different test runs. Next is the regression value of a linear regression line through the data for the current time. Conf is the confidence value for the regress value at a confidence value of three sigma. Lowlim and hilim are the low and high limit values for the current time. The lowlimit value is the Regressed value minus the confidence while the Hilimit value is the regressed value plus the confidence. The lowestest and hitest values are the static lower and upper limits. Finally, three email addresses are listed. These are used to notify metrologists if the new value is outside the limits or the test values.

The data in the limit files are used by the MET/CAL procedures to give the technician instant feedback about the plate.

What the technician sees:

The MET/CAL procedure for routine blackbody (a device that radiates thermal energy) calibration includes the ability to add new assets, add a new emissivity point in the future, as well as email notification of new assets, passed calibration, and failed calibration. The technician calibrates temperature sources using the MET/CAL procedure, which supplies all instructions as well as instant test decisions.

The MET/CAL procedure uses the regressed value for today as the nominal value. The technician no longer has to enter the temperature calibration value manually. In addition, the system actual value updates daily instead of periodically at calibration.

For existing assets that are selected for Control Charting, the procedure verifies which emissivity to calibrate. (See figure 1)



Figure 3 MET/CAL Operator Test Decision Window

If the technician wishes to add an emissivity or if this is a new asset, the procedure allows the technician to select multiple emissivity settings. (See figure 2.)

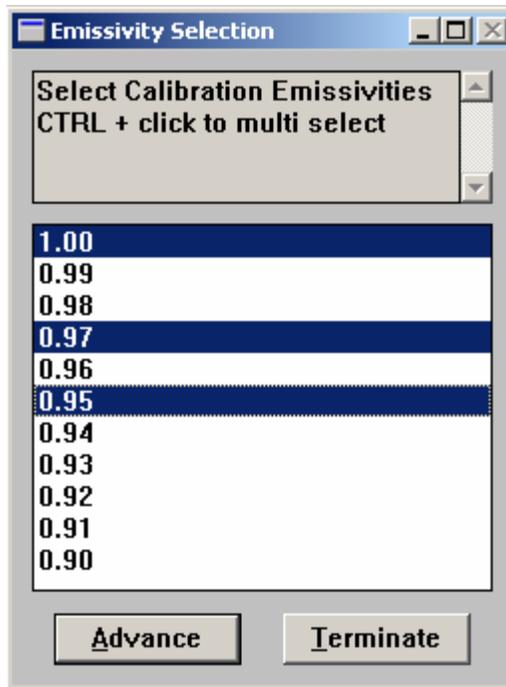


Figure 4: MET/CAL Operator Emissivity Selection Window

The procedure provides instant pass/fail test decision. (Figure 5)

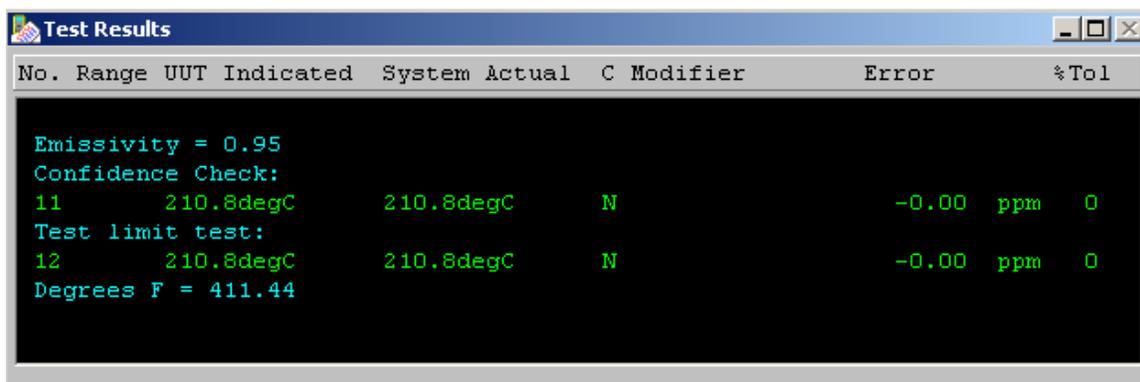


Figure 5 MET/CAL Test Results Window

Example of how to get the regressed value and the confidence from the limit files.

```
# Get the UUT asset number
1.001 MATH ASSET = UUT()
# Build file path for the UUT limit file
1.002 MATH PATH = "C:\\LIMIT_FILES\\CC_" & ASSET & ".CSV"
# Limit file step number
1.003 MATH CC_STEP = 1
```

```

# Attempt to extract limit file data.
1.004 MATH          N = FINDCSVN(PATH, CC_STEP, 1, 1, "STR")
# Check if N is true
1.005 IF           N
# Assign regressed value to MEM1
1.006 MATH          MEM1 = FLD(STR, 2, ",")
# Assign confidence level to L[1]
1.007 MATH          L[1] = FLD(STR, 3, ",")
# Set Tolerance
1.008 TOL           L[1]U
1.009 ELSE
1.010 DISP          No information could be located for
1.010 DISP          step number [V CC_STEP].
1.011 ENDIF

```

ANALYZING THE DATA

The data can still be analyzed using Excel. The get external data feature can be used to get data out of the MET/CAL database without rekeying the data. In Excel, go to Data->Import External Data->New Database Query.

First, pick the data source, which is the same data source used by MET/CAL which is "Calibration Data". After logging in, you are in the MS Query tool. Select file then Execute SQL and enter the command:

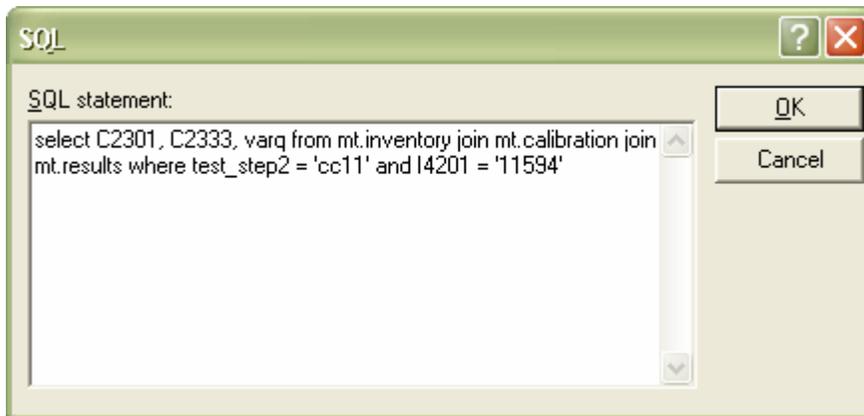


Figure 6 SQL Statement Dialog in Excel

In the SQL statement we are retrieving the Calibration date (field C2301), time (field C2333), and the measured value (varq) out of the results table for asset number 11594 and tag id cc11. On the file menu pick return data to excel. The data can now be manipulated and Control Charted without it having to be reentered.

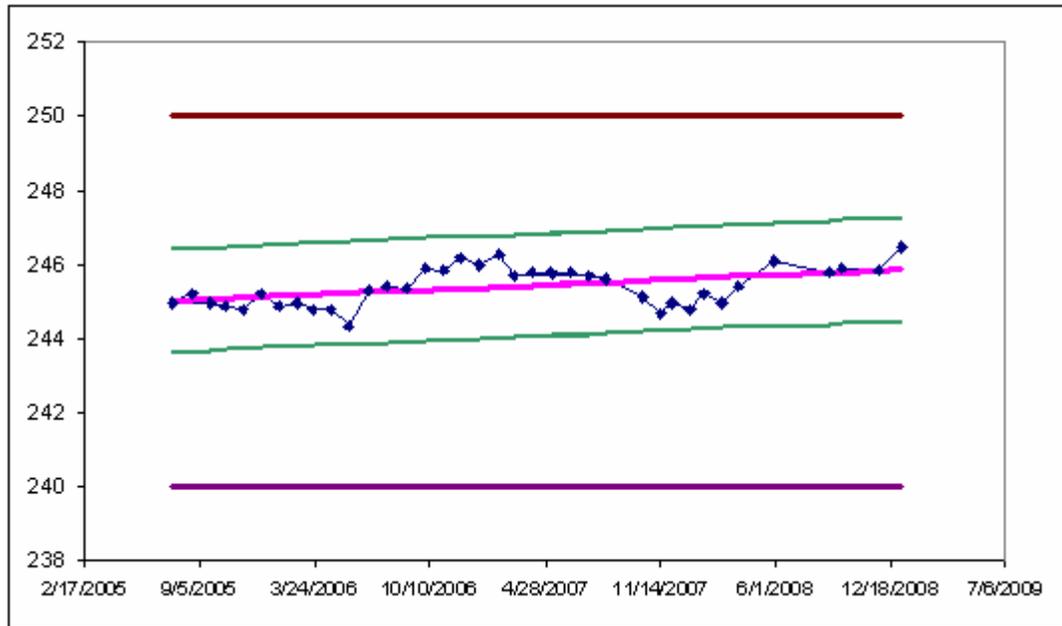


Figure 7 Control Chart in Excel for Asset 11594 Step 11

The Excel spreadsheet can also generate the limit files described above. However, given the large number of Control Charts that Fluke needs to analyze and review on a frequent basis, the Primary Standards Laboratory (PSL) wrote a tool to automate this work.

PSL CONTROL CHART TOOL

The Control Chart tool is a program for working with the Control Charts for assets with tagged data in the MET/TRACK Database. Once asset calibration data is properly configured, the tool can analyze asset parameters. There are two primary parts to the tool: the part that runs nightly as a scheduled task and the Analysis window where metrologists can examine an asset in detail.

The more important of the two pieces is the scheduled task piece. It runs and analyzes the plate data on a nightly basis. The scheduled task creates new limit files for each asset being Control Charted giving the technicians the next day the latest value. The tool also analyzes the OOC band and its relation to the control limits. If the OOC line is about to cross the control limit in the next 60 days an email is sent to the metrologist who monitors that asset. This allows the metrologist to analyze the situation and determine the proper course of action. If the control limit is going to be reached in less than 10 days, then the issue is escalated and the metrologists' supervisor is emailed!

The more interesting part of the tool is the interactive portion. Here a user can interactively examine a Control Chart using the Analysis UI for various asset parameters.

An example main window is shown below. The main window shows the assets that are configured for charting and their current status. In the title bar the name of the database is shown. The first column contains the date the limit file was last written by scheduled task analyzer. If the step information for a Control Chart contains limits, then the Out of Confidence (OOC date) relative to those limits is also shown. In the last column, the step information for this asset is shown.

CC PSL Control Chart Tool : Calibration DataCSS

File View Chart Maintenance Help

Asset Number	Last Report	OOB
11510	01/14/2009	01/14/2012
11513	01/14/2009	01/14/2012
11515	01/14/2009	06/12/2010
11517	01/14/2009	01/14/2012
11518	01/14/2009	01/14/2012
11519	01/14/2009	01/14/2009
11553	01/14/2009	01/14/2012
11594	01/14/2009	05/17/2009
11595	01/14/2009	12/15/2009
11596	01/14/2009	04/20/2010
11597	01/14/2009	02/12/2010
11598	01/14/2009	12/29/2009
11599	01/14/2009	01/12/2012
11600	01/14/2009	03/27/2010
11601	01/14/2009	01/14/2009
11603	01/14/2009	04/08/2009
11612	01/14/2009	
11613	01/14/2009	
11614	01/14/2009	
11615	01/14/2009	
11616	01/14/2009	01/14/2012
11620	01/14/2009	03/13/2009

11594

Figure 8 Control Chart Tool Asset Window

To view the Control Chart for an asset, double click on row, or select then menu items **chart** and then **row**. This takes you to the Control Chart Analysis Window.



Figure 9 Control Chart Tool Analysis Window for Asset 11594 Step 11

The Control Chart analysis window is used to interactively look at the Control Chart for different steps for a given asset. Step data can be marked as ignored and the data recomputed.

The data points for the plot are shown on the left side of the screen. The first column is the calibration date for that point relative to today. The second column contains the value, and the third column (not shown by default) contains the calibration date. Points can be dynamically included or excluded from the plot by checking a checkbox picking the Go! menu item.

The Control Chart plot is shown to the right of the data. The plot includes the data points, a regression line through the data, confidence bands around the data, and limit lines if there are limits in the step info.

Also to the left of the data points and below the plot the step information associated with this asset is shown. Double clicking on a row in the step information will show data for that step in the data area, and plot the Control Chart for that step in the plot area. The step information grid contains the step number and its description, The confidence interval about the regression and the regressed value at the point on the right of the plot. Also shown are the low and hi test limits (if they are in the step information), and the Out of Confidence date.

The status bar at the bottom of the window displays messages about the data. In this example we see there are duplicate tags on steps in the data, which should be corrected. The system only shows one point per step per calibration event.

IT WORKS!

One of the first pieces of equipment Control Charted with the new process was the service centers thermo gauge (T-gauge), a blackbody furnace used to source 2000 C radiation. The T-gauge has a graphite tube with a partition in the center of it, creating a dual cavity. A control pyrometer is mounted

on one end and sends information to the controller which controls the current across the tube. The UUT is mounted on the other end of the tube. The graphite tube typically only lasts 30 to 120 days.

Daily checks are performed at 3 temperatures on the T-gauge which are Control Charted. Recently the Control Chart tool notified the metrologist that the T-gauge would be out of confidence in less than 20 days. Upon examining the data it was obvious that the data was much noisier than previous readings, prompting the ordering of a replacement element. A few days later, the daily checks failed the test limits. The technician inspected the T-gauge element and found a hole had formed on the control pyrometer end, and that the walls were thinning in some areas. Because a replacement element had been ordered the unit was rebuilt with minimal disruption to production.

CONCLUSIONS

Control Charts are a useful tool to track expected values of references.

There were many issues that needed improvement in the temperature plate process. Through the Kaizen process these issues were examined and greatly improved.

Originally a metrologist was spending over 40 hours per week updating 200 Control Charts and analyzing data. This time has been reduced to 3 hours per week and the number of Control Charts is now closer to 300.

The approval process for a new plate value was taking at least three days. The new approval process has reduced the approval time to zero! The MET/CAL procedure uses limitfile data that is compiled nightly. This gives technicians instant feedback that a measurement may be suspect and indicates if systems are in control. If a plate fails, the metrologist is also sent an email so proper corrective action can take place.

In addition, future values are projected for each plate every night. Those projections are compared to the limit values, and email is sent when the projected values will be out of tolerance in less than 20 days. This allows for preventative actions to be taken before catastrophic failures occur.

REFERENCES

[1] Crow, Edwin, et al., Statistics Manual, Dover Publications, Inc, New York, 1960.

[2] Mason, Nicholas, Maintaining InSitu Traceability on the Factory Floor with Process Metrology, Measurement Science Conference, 2008

[3] Montgomery, Douglas, Introduction to Statistical Quality Control, John Wiley and Sons, Inc., 1985