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MAINTAINING IN-SITU TRACEABILITY ON THE FACTORY FLOOR WITH PROCESS METROLOGY

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In the mid 1990's, Fluke proposed a method for maintaining factory test systems without requiring the traditional periodic recall of each reference in the system [1]. This method, called Process Metrology is a means to establish traceable calibration of factory test systems on the factory floor.

Process Metrology was born out of the need to calibrate high accuracy calibrators on the factory floor without having to stop production for factory station maintenance and minimize the need for spare, high cost test equipment. At that time, it was unclear whether Process Metrology was cost effective and would meet its goals [1,3].

Process Metrology has met its goals. It has also provided benefits that were not obvious at the beginning and is standard practice on many production lines. This paper reviews and discusses the current state of Process Metrology at Fluke. Examples from a new 6.5 digit meter are used.

INTRODUCTION

The Fluke factory in Everett, WA recently started producing a new 6.5 digit meter product, the 8846A. Production started by using traditional metrology on the five factory consoles used to adjust and verify the units. However, the factory soon switched to using *Process Metrology* for 8846 production. This paper describes Process Metrology, the tools used to implement it, and its effect on 8846 production.

WHAT IS PROCESS METROLOGY?

Process Metrology is a quality control process used to calibrate test consoles on the factory floor. It is an alternative to the traditional method of periodically removing references for calibration. A functional block diagram of the Traditional and Process Metrology systems is in Figure 1.

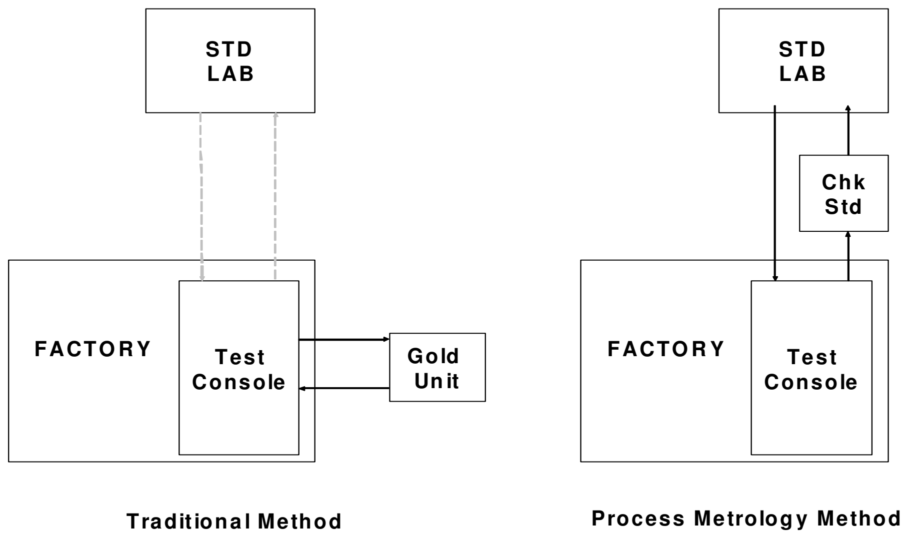

Figure 1 Traditional and Process Metrology Functional Diagram

Traditional Method

In the traditional method, each piece of reference equipment is periodically removed from the console and returned to the calibration lab. This has several disadvantages. The Factory Test Console is out of service while being calibrated and no products can be produced. This means that replacement references must be available to keep production going. In addition, calibration occurs at regularly scheduled intervals whether the equipment is really going out of specification or not. Finally, functions are calibrated that may not be required by the product being produced.

Each 8846 factory console contains three references on 90-day recall. Thus in any 90 day period, 15 references must be removed from the factory consoles and sent to the service center for complete calibration. A complete calibration is performed even though the factory console do not use every function and range from each reference.

To help ensure the consoles are not building bad products their health between calibrations of the references is checked. This is accomplished by regularly measuring a known good unit, also known as a “gold” unit on the test console. If performance is within the product test limits for all parameters, the test console is proclaimed fit for use. One console is tested each day so that all of the consoles are tested by the end of the week.

Process Metrology Method

Process Metrology is a technique where the entire calibration process is monitored for compliance to the test limits rather than monitoring the product. If the process shows signs of going out-of-confidence (OOC) it is then time to take action.

One choice is to take the consoles off line and calibrate the references. Another choice is to apply *correction values* to the test console to compensate for drift of the references. If this method is used then the factory console software must be able to use corrections supplied by the Annex Lab Deputy. This is the method used on the 8846 production line.

In addition to compensating for drift of the references, Process Metrology is also better at accounting for all of the uncertainty in the system. For example, Process Metrology takes into account system uncertainty due to interconnections and automated switching systems in the test console. The overall manufacturing process is more stable because references are not removed from the console, taken to the Laboratory for calibration, and then replaced into the console.

Process Metrology requires measuring *check standards* on the Test Consoles and Standards Laboratory on a periodic basis and analyzing the resulting measurements [3]. Check standards are devices used to transfer measurements between the factory console and the laboratory. Check standards are typically the product manufactured on the factory console. Having the check standard the same type of instrument as the product calibrated on the factory console reduces the risk of the effects of different loading from different types of instruments.

The check standard is first measured in the factory and then in the Standards Lab for the same parameters. Recall that the traditional method requires measurements of a gold unit on the factory console. To implement Process Metrology only one additional set of measurements is made in the Standards Laboratory. Check standards are measured in the factory and Standards lab weekly.

These check standards are always the same instruments. This assists with troubleshooting problems that occur in the system. The check standards are the same as the product being built so that its contribution to the random measurement noise is typical of product. Having the check standards the same type of instrument as the product also reduces the risk of the effects of different loading from different types of instruments. The Annex Lab Deputy computes *limit files* based on the historical readings of the check standards on the factory and standards lab systems. While the systems are measuring parameters on the test systems, the measured values are compared to these limits. If they are outside the limits the system operator is alerted and the problem corrected. This helps to ensure the quality of the measurements. It also means that drift of the check standards themselves is not a factor in the process.

The difference between the factory and Standards Lab measurements represents the performance of the factory test console relative to the standards maintained by the Standards Lab, referred to as the *difference data*.

To quantify the performance of the test console relative to the Standards Lab standards, the Annex Lab Deputy performs statistical analysis of the *difference data*. Linear regressions and confidence bands about the regression are the primary tools used to analyze the data. The present value of the regression line represents the best estimate of the Annex Lab test console error relative to the Standards Lab. The regression is the basis for making *corrections* to the factory test console.

Any irregularities that occur in the difference data suggest a change in the check standards, the test console, or the Standard Lab and warn the Deputy to investigate further. Sudden shifts or aberrations in the difference data is used to predict problems before they occur. More on this later.

The confidence bands predict the out-of-confidence date for the test console as they include the uncertainty of the Standards Lab measurements, the product performance distribution and the factory test console [1].

The constraint of product tested on the factory test console is that its actual error must be less than the *test limit* or L_{spec}. The total error consists of three elements, (1) the error of the product relative to the test console, (2) the error of the test console relative to the Standards Lab and (3) the error of the Standards Lab relative to national labs or intrinsic standards as shown in equation 1:

$$mX + b \pm k \cdot \sqrt{U_{sl}^2 + U_{diff}^2 + U_{prod}^2} \leq L_{spec} \quad (1)$$

Where:

$mX + b \pm k \cdot \sqrt{U_{diff}^2}$ = error of the test console relative to the Standards Lab, as characterized by a linear regression.

U_{sl} = The error due to the uncertainty of measurements in the Standards Laboratory.

U_{prod} = The error due to the uncertainty of the product relative to the factory test console.

k = coverage factor of 2.

As long as Equation 1 is true, the Test Console can build good product. Control charts for each parameter under test are made using Equation 1. Figure 2 shows an example.

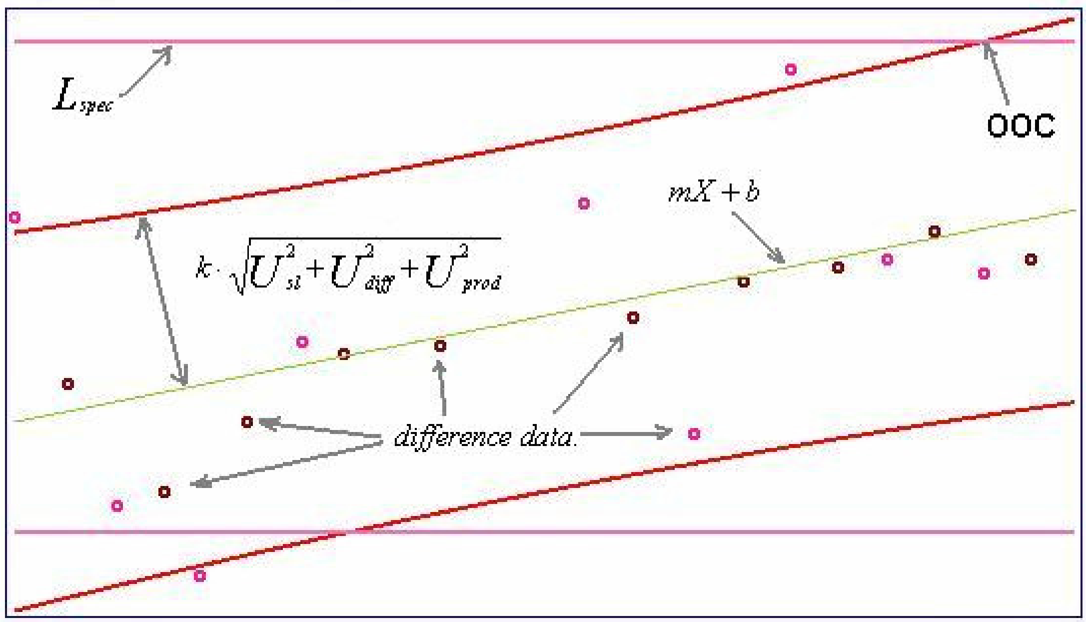

Figure 2 Test Point Control Chart.

In Figure 2 a sample difference data plot is shown for one parameter on a console. All Process Metrology analysis is relative to today, so the X-axis contains days backwards from today. Each data point is approximately week apart, representing the weekly measuring of the check standard on the console and the Standards Lab. The Y-axis is relative to the product test limits.

In the plot above, there are two check standards, whose data points are circles on the plot. Also shown are the regression line and confidence bands through the difference data. The test limits are two horizontal lines. When the confidence line crosses the test limit line the step is out-of-confidence (OOC) [2]. The value on the X axis where this occurs is the out-of-confidence date.

Before the test is out-of-confidence, corrections are applied to the test console. The correction value is the opposite of the intercept (-b), i.e. the value required to center the regression line today.

PROCESS METROLOGY TOOLS

The Process Metrology calculations for any single parameter are not too difficult. However, the volume of data that is collected and processed can seem overwhelming. There are over 220 test points for the

8846 product, and five test stations. This results in over eleven hundred data sets processed on a weekly basis just for this product. Not something to be done in Excel!

Obviously, effective use of Process Metrology requires automated systems capable of collecting, processing, and then using the resulting output. The Annex Lab Deputy uses Process Metrology tools to process and analyze data on a weekly basis. These tools process the incoming difference data and produce summary, yield and plot reports that the Deputy can examine. The tools also create output the test consoles can use, as they have been designed to work together. Output used by the test consoles includes soft corrections and check standard limit files.

A key tool for the Deputy is Visual PMET. Visual PMET allows the Deputy to see the process metrology status of a given product. An example screen of VPMET is shown in Figure 3. In this example summary information for the five 8846 stations are shown.

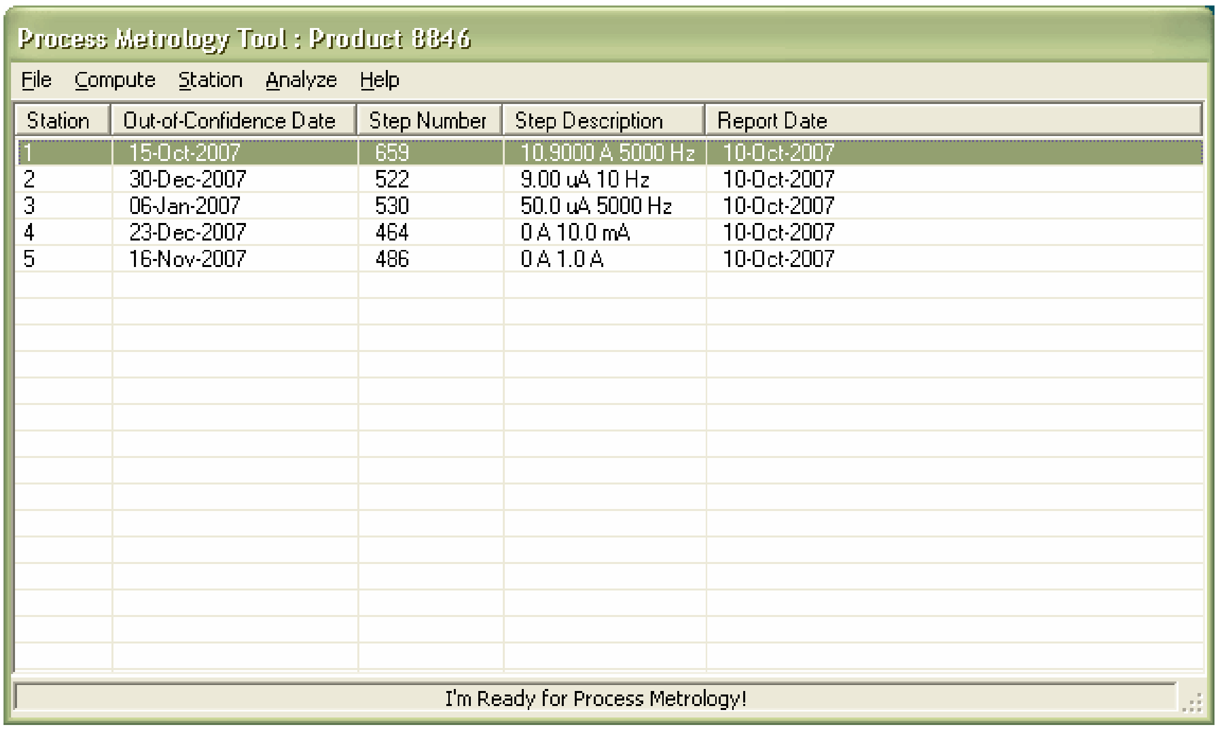

Figure 3 Visual PMET Summary Screen.

At a glance, the deputy can view the status of each station. the out-of-confidence (OOC) date, and the step that will cause Process Metrology to go OOC. Also shown is the last date a report was run.

A Yield report and summary plot is also created for each station. Many products at Fluke are using process metrology. Examining every Yield report and confidence plot can be a time consuming task. The deputy needs to know where to spend his efforts and look at the problem areas first. By examining the product summary the deputy can optimize his time and work on problem areas. If the summary indicates a problem the next step is the yield report.

Yield reports and confidence plots

Yield reports and confidence plots are the primary tools used by the Annex Lab Deputy to look at the details of the health of the system. These reports determine of the Out of confidence date for the Test Console and assist in detection of OOT conditions for instruments or for the test console itself.

An example Yield report in Figure 4:

```
Primary Standards Laboratory Process Metrology Report: 10/15/2007 5:50:17 AM

Product  : 8846
Station  : 2

95% OOC steps     :
OOC < 20 days     :

=== OOC Detail ===
Total Uncertainty at 95% Confidence
Udiff, Usl, Uprod at K = 1
                                    OOC    OOC          % of Limit
Step  Description                   Days   Date       Utot  Udiff  Usl  Uprod

 522: 9.00 uA 10 Hz                   30  14-Nov-2007   88     13   28   31
[9223020: Fluke 5720A: 12 pts 70%(f) 9%(s) ]
[9292014: Fluke 5720A: 9 pts 6%(f) 11%(s) ]

 442: 0 A 100.0 uA                    45  28-Nov-2007   72     11   14   31
[9223020: Fluke 5720A: 12 pts 35%(f) 49%(s) ]
[9292014: Fluke 5720A: 9 pts 35%(f) 35%(s) ]

 464: 0 A 10.0 mA                     64  17-Dec-2007   70     17    2   31
[9223020: Fluke 5720A: 12 pts 26%(f) 66%(s) ]
[9292014: Fluke 5720A: 9 pts 62%(f) 42%(s) ]
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Figure 4. Sample Yield report.

Process metrology tools calculate metrics to determine the status of the Annex Lab test console yield. The console is said to be “In Confidence” when the calculated yield is less than or equal to the desired confidence level. The goal is to achieve 95% confidence. The yield does not drop below a 95% confidence level without prior approval.

The Yield report is a summary of the current state of a station. There is one yield report for each station. Each report has a header showing the station summary and an OOC detail section. The header indicates the date and time of the report run, the product and station, and a summary of test points that need further examination. The summary including steps that are out of 95% confidence and steps soon to be out-of-confidence (typically 20 days). The report lists other information to help determine the cause of the out of confidence condition. Included are the uncertainty components as a percentage of test spec and days until out of confidence. Noise performance is also broken down by check standard and by Standards Lab and Annex Lab to help isolate problem areas.

At the time of this report, we have 30 days until test point 522, 9 uA at 10 Hz goes out-of-confidence. For more information, we look at the confidence plots. An example confidence plot is in Figure 5.

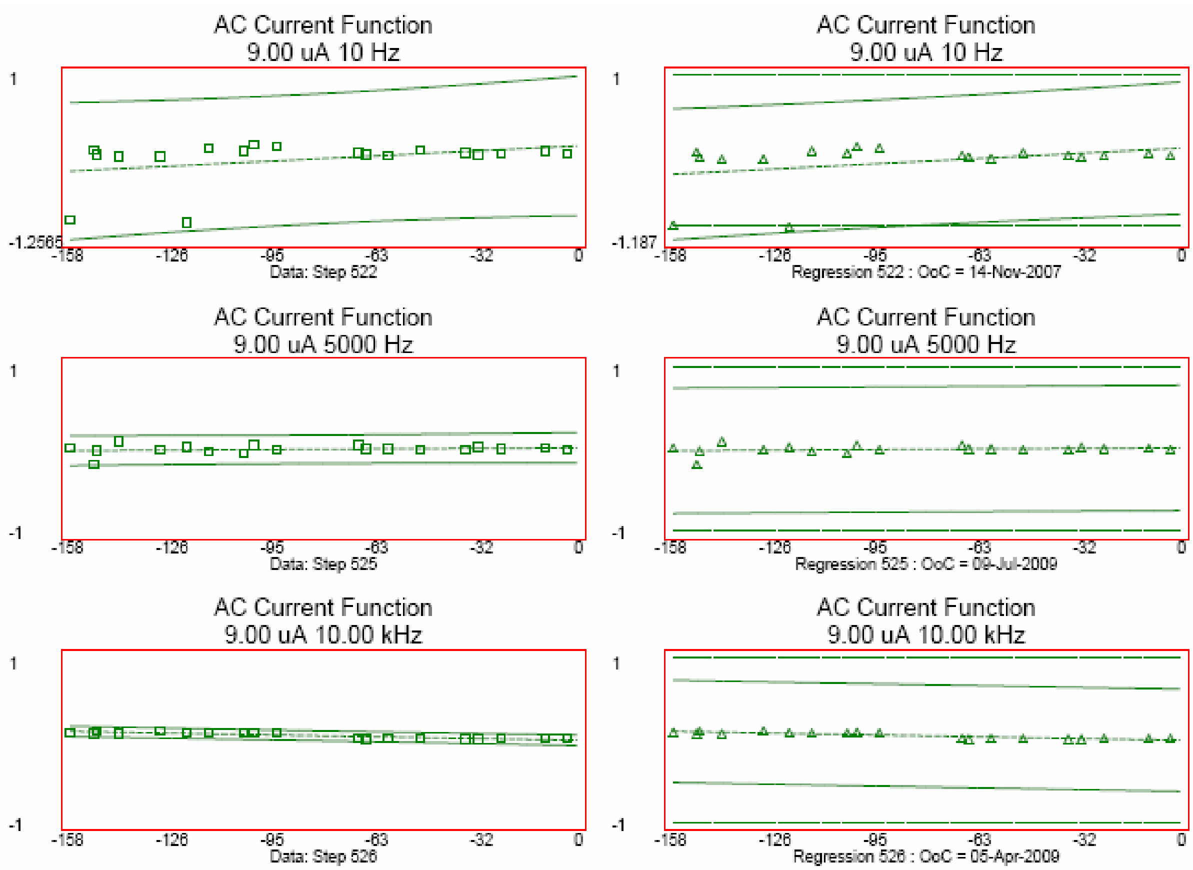

Figure 5. Confidence Plot for steps 522, 525 and 526

The confidence plots contain two plots for each data set, the left side plot and the right side plot. The left side plot shows the individual difference data points, a regression line for the difference data, and data confidence bands (not regression bands), which help identify faulty data and undesirable data patterns. They are scaled in units normalized to the process metrology specification.

The right side plot also shows the individual data points and the corresponding regression line. This plot shows the regression confidence bands, and the OOC limits as described for Figure 2.

Based on the yield report, test step 522 is the first point to go OOC in 30 days. Examining the confidence plots indicates this may not really be the first OOC point. Figure 5 for step 522 shows that there are two outlier points, one about 126 and the other about 158 days ago. No other data points in the last 158 days have values similar to these points, so the Annex Lab Deputy may decide that these are outlier points and remove them from the data set. Once this is done the OOC date for step 522 can be recomputed.

Calibration correction values

The process metrology tools generate a correction file containing the correction values for each parameter. To apply corrections to the Annex Lab test console, this file is installed at the console's workstation. The test console software shall use this file to add the proper correction value to the raw measured value when testing an instrument. This sum is the reported measured value that gets written to the data file and printed out on the calibration certificate.

When characterizing the test console as described in the preceding section, the historic transfer standard data files used to calculate difference data will have different correction file revisions. In order to maintain continuity of data during the regression analysis, all historic data is adjusted to reflect the most current corrections.

Local limits for check standards

Local limits files allowing for the drift and individual characteristics of each check standard are computed. When the check standard is run on the test system, the values need to fall within the local limits, or it is most likely a "bad" reading. This alerts the technicians to examine the data points that fail local limits, and retest those points if necessary.

SUMMARY

Process Metrology started out as a theoretical idea to solve the problem of calibrating high accuracy references on the factory floor and maintain uncertainties that would be difficult to do any other way.

Today Process Metrology is a key manufacturing technology used within the Fluke Corporation to facilitate manufacturing operations and provide a competitive advantage.

Advantages of Process Metrology include the following:

- Process Metrology monitors the performance of the overall system including the effects of the operator and the instrument-system interface. OOT conditions are detected quickly.
- The tools compute out-of-tolerance dates for the worst performing parameters and corrections are computed by the system and used by the test consoles.
- The production process is monitored very closely. Over 1100 test points are examined on a weekly basis ensuring product meets the test specifications.
- The need for reserve references and system down time is minimized. The time and expense of routine calibration is eliminated. Fewer reserve references saves significant cost.
- The system references benefit from not being removed and moved around. The references are only calibrated at the points used by the product being built.
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REFERENCES

[1] Kletke, Ray, Maintaining Traceability at Remote Sites with Process Metrology, NCSL Workshop and Symposium, 1995.

[2] Artifact Calibration, Theory and Application, 1996, Fluke Corporation

[3] Huntley, Les, An Application of Process Metrology to the Automatic Calibration of Instruments, Measurement Science Conference, 1987.