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Process Measurement Assurance Program

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Richard B. Pettit

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Process Measurement Assurance Program

Richard B. Pettit
Primary Electrical Standards Department
Sandia National Laboratories
Albuquerque, NM 87185

Abstract

This paper describes a new method for determining, improving, and controlling the measurement process errors (or measurement uncertainty) of a measurement system used to monitor product as it is manufactured. The method is called the Process Measurement Assurance Program (PMAP). It integrates metrology early into the product realization process and is a step beyond statistical process control (SPC), which monitors only the product. In this method, a control standard is used to continuously monitor the status of the measurement system. Analysis of the control standard data allow the determination of the measurement error inherent in the product data and allow one to separate the variability in the manufacturing process from variability in the measurement process. These errors can be then associated with either the measurement equipment, variability of the measurement process, operator bias, or local environmental effects. Another goal of PMAP is to determine appropriate re-calibration intervals for the measurement system, which may be significantly longer or shorter than the interval typically assigned by the calibration organization.

Introduction

The current emphasis on manufacturing high quality products requires ensuring that the product meets its specifications with regard to performance, reliability, and competitiveness. For this determination, one must measure all of the important product attributes in order to quantify the quality of the product. During manufacturer, the product data are usually analyzed using standard statistical methods, such as Statistical Process Control (SPC) or Six-Sigma (6σ) techniques [1], in order to minimize product variation due to process variables. This leads to continuous improvement in the production process and the resulting product. However, the product data accuracy can not be better than the accuracy (or uncertainty) associated with the measurement system used to measure the product. In most cases, one would like the measurement system accuracy to be much smaller that than the product specification (e.g., measurement system accuracy of 0.01% for a product specification of 0.1%). Thus in the final analyses, the quality of the product is directly related to the quality of the measurements.

There are two criteria that define the quality of the measurement data: First, the traceability of the measurements and secondly, the uncertainty of the measurements. The traceability of the measurement system is ensured by calibrating the measurement system using standards and procedures that are correlated with national and/or international standards usually maintained or determined by the National Institute of Standards and Technology (NIST). However the uncertainty in the data obtained from the measurement system is much more difficult to determine, especially considering all the factors of the production environment that can effect the measurement. Even though the equipment is calibrated, the measurements can be biased from the true value due to environmental effects (temperature, humidity, etc.), the measurement process (fixtures, procedure, corrections, span adjustments, etc.), or operator offsets.

The traditional approach to determining the measurement system capability relied on Reliability and Repeatability (R&R) studies [1], however they do not determine the overall measurement system uncertainty. R&R studies only determine the randomness of the measurement process (repeatability) and the variation from operator to operator (reliability). Factors not considered that may contribute to the overall uncertainty of measurements include the capabilities of the measurement equipment, the measurement process or procedures used, any standards used, the calibration technique and calibration frequency, operator knowledge and biases, and other quality control procedures. A process, called the Process Measurement Assurance Program (PMAP), has been developed which determines both the overall uncertainty in the measurements and in addition ensures that the measurement system remains in control. The remainder of this document briefly describes the PMAP process, its advantages, and additional considerations.

PMAP Process

The PMAP process was developed and used at Mound Laboratories for the control of production equipment by Jerry Everhart, now with JTI Systems. [2] The purpose of PMAP is to improve the quality of products by building quality into the measurement process, thereby ensuring that product specifications are being met. Traditionally manufacturers rely on Statistical Process Control (SPC) techniques to control the variations in the production manufacturing process. All of the SPC data are obtained using a measurement system that itself contributes variability and biases in the resulting data. PMAP is used to characterize the measurement system variability and any associated measurement errors (or the overall measurement uncertainty) so that the characteristics of the measurement system can be evaluated and separated from product variations. By introducing PMAP controls into the measurement process, an understanding of the overall uncertainty of the measurements increases one's confidence in the product data.

The PMAP process involves introducing into the measurement process a control standard that is developed specifically to represent the product characteristic being measured. The development of this standard is usually a joint effort involving metrology, production, and design personnel. The calibration (metrology) laboratory characterizes and certifies the control standard and assigns to it both a value and an uncertainty. After the measurement system has been calibrated, the control standard is periodically measured by production personnel using the same measurement process and equipment that are used to measure the product. These data are plotted and monitored using SPC techniques in order to ensure that the measurement system is in control and thus does not have to be recalibrated. By comparing the data measured for the control standard with its value assigned by the metrology laboratory, the overall uncertainty of measurement system can be obtained.

Some important characteristics of the control standard include:

- The control standard should be designed to mimic the product feature being measured as closely as possible.
- The control standard should have long term stability.
- The control standard should be developed by both production personnel, who have knowledge of the product requirements, and metrology personnel, who have knowledge of standards.
- Both the value and the uncertainty (accuracy) of the control standard must be determined (using a process similar to that discussed in reference [3]). One would like the uncertainty in the control standard at the level of the readability of the measurement system, if possible.
- The same measurement process should be used for the control standard as for the product (zeroing of equipment; fixtures; software; data analysis; etc.). Thus the control standard should be subjected to the same environmental influences, measurement process, and operators that are used to measure the product.

Differences between the measured value and assigned value for the control standard are related to biases (offsets) in the measurement process. Once understood and quantified, these offsets can be corrected or adjusted in order to improve the quality of the measured data. Alternatively, large biases may indicate that the measurement system needs to be recalibrated or that the measurement process is defective and must be improved. By monitoring the measured value of the control standard over an extended time frame, the random effects on the measurement system due to the environment, the measurement process, and different operators can also be determined. These two results are used to determine the overall measurement uncertainty of the measurement process. This value can then be compared to the product specification and the product manufacturing variations.

Measurement data for the control standard are monitored and recorded using procedures similar to product SPC procedures. Measurement control limits for the control standard must be determined, usually right after the measurement system is calibrated and can be performed by metrology staff. When the control standard satisfies the above characteristics, these limits inform the production operator whether the measurement system is in control and thus provides high confidence in the product data. Software programs and systems are available for recording, monitoring, and displaying the measurement system control data. These data can be monitored by both the production personnel and the metrology personnel.

PMAP Advantages

Major advantages of using the PMAP control standard to monitor the measurement system include the following:

1. The reliability and quality of the product data are enhanced because control standard data demonstrate that the measurement system is in control.

2. The overall uncertainty in the measurement system data is determined. There are basically two sources of errors in the measurement: biases and randomness. Biases are determined by comparing measurements of the control standard with the value assigned by the calibration laboratory. Randomness in the measurement process is determined by calculating the standard deviation of the measurement results over extended time periods. Combining the random and bias uncertainties, together with the calibration uncertainty of the control standard, allow one to assign an overall uncertainty to the measurement system.

3. The adequacy of the measurement system is determined by comparing the overall measurement uncertainty with the product specification. If the measurement system uncertainty is too large, variations in the production process or product data can not be separated from variations in the measurement system itself. Therefore, either the product specification must be increased or the uncertainty of the measurement system improved. Improvements can usually be obtained is several ways, for example, by improving the environmental control (temperature, humidity, vibration, etc.); modifying the measurement process (for example, including buoyancy corrections in mass measurements, temperature correcting data, etc.); training the operator in better measurement techniques; or improving/replacing the measurement equipment itself.

4. Continuous and immediate feedback is obtained on the status of the measurement system. If the control standard measurements are outside their control limits, the measurement system is

out of control. Since this fact is detected early, it can be corrected before a substantial amount of product is manufactured. In addition, the data can be checked for correlation with the operator, environmental effects, measurement system changes, or problems with the control standard itself.

5. Retesting product is minimized if the measurement system drifts out of control since the time when the system went out of control is known. Thus only a limited amount of product needs to be remeasured when problems are found with the measurement system.

6. By understanding the measurement system, variations in the production process can be separated from variations in the measurement system. In this way the production process can be continuously improved. In addition, the control standard data allow the measurement system and measurement process to be improved.

7. Inspection and additional acceptance measurements of the product should become unnecessary because of the high confidence in the data obtained from the measurement system. Thus valuable time and the cost of additional inspection equipment can be saved. The control standard closes the loop on the measurement system's performance before the product is moved from one production station to the next.

8. The calibration interval for the measurement system can be optimized since the control measurements continuously monitor the calibration status of the measurement system. For example, if it is found that the measurement system is drifting out of calibration, the calibration interval can be shortened. On the other hand, if the measurement system is very stable, the calibration interval can be lengthened. This puts intelligence into the calibration interval determination.

9. The PMAP process bridges the gap between the calibration laboratory and the production environment. Traditional calibration of individual pieces of equipment in the calibration laboratory does not check for interactions between different pieces of equipment operating in the production environment.

Additional Considerations

There are several additional considerations that need to be understood with regard to implementing the PMAP process:

1. Metrology, design, and production personnel should be involved early in the process of selecting the measurement system. This will ensure both that the measurement equipment can be adequately calibrated by the calibration laboratory and the equipment is capable of the desired level of measurement uncertainty. In addition, metrology personnel can assist in developing the overall measurement process, designing test fixtures, and selecting the control

standard, as appropriate. Metrology personnel may also assist with the product design measurements, since these measurements are used to set the product specifications.

2. After the measurement system has been calibrated, repeated measurements of the control standard should be obtained in order to define the initial control limits for the control standard. When the system is operated by the production personnel, measurements of the control standard are compared to these control limits in order to determine if the measurement system is still in control.

3. The fist measurements of the control standard should be correlated with a complete calibration of the measurement system. Then if the control standard results remain in control, the measurement system should not require recalibration, thus lengthening the calibration interval. On the other hand, the control standard may only check a limited range of the measurement system so that a periodic calibration may be needed to ensure that all the measurement functions are operating properly. For example, a calibration of a voltmeter may check the voltage range from 0 to 100 volts full scale, while the control standard may only determine the performance at the 10 volt level.

4. The use of control standards may not be appropriate for all product measurement systems because of the additional costs and time to implement and track these data. Certainly measurements of critical product parameters are candidates for implementing a PMAP process, as well as any state-of-the-art measurements. In addition, the PMAP process should be used when information of the overall measurement uncertainty of the measurement system are desired.

5. The schedule for performing measurements of the control standard should sample as many of the measurement conditions as possible. Thus, taking measurements only in the morning may not sample all the environmental conditions as compared to measurements scattered through the day. In addition, the measurement system or operator technique may change during the production process; these variations should be sampled.

6. Many processes and procedures may already have existing control measurements. In this case, considerable value may be added by control charting these data and applying the PMAP data analysis process with little if any additional costs.

7. Periodically the control data should be analyzed to determine if either the variability or any bias in the data have changed (using t and F tests). In order to verify the long term stability of the measurement system, either the measurement system or the control standard may need to be re-calibrated. The frequency of these re-calibrations are determined by the stability of the measurement system and the control standard.

Summary

PMAP provides a new powerful tool for building metrology into manufacturing processes. It contributes to an increased confidence in product data, as well as determining the overall measurement system uncertainty. In addition, PMAP puts intelligence into the calibration interval determination. It is clearly a value-added feature that needs to be integrated into product realization processes where appropriate.

References

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2. J. Everhart and R. Rios, Process Measurement Assurance Program (PMAP) Seminar, JTI Systems, Albuquerque, NM 87106.

3. B. N. Taylor and C. E. Kuyatt, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, NIST Technical Note 1297, January 1993.

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