

SEMI M27-96

PRACTICE FOR DETERMINING THE PRECISION OVER TOLERANCE (P/T) RATIO OF TEST EQUIPMENT

1 Purpose

1.1 This practice covers a procedure for estimating the capability of a test instrument with respect to the tolerance (specification) of a parameter.

NOTE 1: If the variability associated with the measurement of the parameter by this instrument is very small compared with the width of the specification range, the chances of obtaining a test result outside the specification limits when the parameter actually lies within the specification limits (or conversely) is quite small. On the other hand, if this variability is too large, the probability of obtaining a false test result is much greater.

2 Scope

2.1 This practice provides a standardized method for determining the relationship between the measurement precision of a single instrument and the specification range.

2.2 The ratio of precision to tolerance (P/T) can be used as a measure of the suitability of a measurement process to evaluate a specific parameter against a given specification. Calculation of the P/T ratio requires knowledge both of the precision of the measurement process and of the specification range or tolerance of interest.

NOTE 2: If the tolerance has been arbitrarily defined without regard to process variability or other considerations, the P/T ratio might be meaningless.

NOTE 3: Another metric for the suitability of test equipment is the signal to noise (S/N) ratio, which relates the process variability to the measurement variability; consideration of this metric is beyond the scope of this practice.

NOTE 4: The P/T ratio does not provide any information about the bias of the test instrument being evaluated; hence, it is not a suitable metric for test instrument accuracy.

2.2.1 A procedure is given for estimating the overall measurement precision of the measurement process as carried out by an automated (self-calibrating) or non-automated (non-self calibrating) test instrument under the conditions normally encountered in applying the instrument. No information is developed concerning the components of the precision; consequently, this practice cannot be used to determine the origins of measurement variability. Such information can be developed through the use of a full measurement capability analysis such

as a properly designed gauge repeatability and reproducibility study.¹

2.2.2 Both double-sided and single-sided specifications are covered by this practice.

NOTE 5: It is not meaningful to compare P/T ratios between single-sided and double-sided specifications of the same parameter.

3 Referenced Documents

3.1 SEMI Standard

SEMI M1 — Specifications for Polished Monocrystalline Silicon Wafers

4 Terminology

4.1 *accuracy* — The closeness of agreement between a test result or the mean of a group of test results and the true value (accepted reference value).

DISCUSSION — Accuracy depends on both precision and bias of the measurement process. Since in routine use, random components of error (resulting in imprecision) and systematic components of error (resulting in bias) cannot be completely separated, the reported accuracy must be interpreted as a combination of these two elements. In part, because of the inability to separate the random and systematic components of error, the ISO Guide to the Expression of Uncertainty in Measurement² separates uncertainty components of a measurement result into two categories (Type A and Type B) based on their method of evaluation. Type A uncertainties are those that are evaluated by the statistical analysis of a series of observations. Type B uncertainties are those that are evaluated by other (non-statistical) means.

4.2 *bias* — The systematic difference between the population mean of the test results from a measurement process and the accepted reference value of the property being measured.

1 Steven A. Eastman, "Evaluating Automated Wafer Measurement Instruments," in Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A. C. Diebold, eds. (AIP Press, Woodbury, NY, 1995) pp. 248 - 251.

2 ISO/TAG 4/WG 3 Guide to the Expression of Uncertainty in Measurement (October 1993), available from ISO Central Secretariat, C. P. 56, CH-1211 Genève 20, Switzerland, or (in the U.S.) from American National Standards Institute, 11 West 42nd Street, 13th floor, New York, NY 10036. Also see: Barry Taylor and Chris Kuyatt, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, 1994 Edition, NIST Technical Note 1297 (September 1994).

DISCUSSION — One or more systematic error components may contribute to the bias. Because the population mean involves the totality of all possible test results, it cannot be determined directly. The sample mean, $\bar{x}$ is an unbiased estimator of the population mean.

4.3 precision — A measure of the variability of a measurement process about the mean value of the test results obtained.

DISCUSSION — For purposes of this practice, the precision of the test instrument is quantified as 6 times the sample standard deviation of a set of individual test results made under conditions typical of those encountered in the normal use of the measurement equipment being evaluated. Among other factors, drift between instrument calibrations and known and unknown variabilities caused by ambient conditions must be considered. If the data set consists only of a small number of samples, the estimate of precision may be in error.

4.4 tolerance — The absolute magnitude of the range of the product specification.

DISCUSSION — Tolerance and specification are sometimes used interchangeably. Certain industries prefer one term to the other. In some cases, in particular in SEMI M1, the tolerance is given in terms of the deviation from the mean. For the purpose of this practice, the tolerance is always the full range of the specification.

5 Procedure

5.1 Determine the Tolerance (T)

5.1.1 For a double-sided specification, calculate T from:

$$T = USL - LSL$$

where USL is the upper specification limit and LSL is the lower specification limit ($USL > LSL$). If the specification is given as "DIMENSION," $T = 2a$.

5.1.2 For a single-sided specification with only an LSL or USL , take T as the magnitude of the LSL or USL .

5.2 Determine the Precision (P)

5.2.1 Ensure that the test instrument being evaluated is under acceptable statistical control by the methods customarily employed to evaluate the state of control of test instrumentation in the laboratory carrying out the evaluation.

5.2.2 Make a series of measurements of the desired parameter on a test specimen with the test instrument being evaluated under conditions and for a period of

time typical of those encountered in use of the test instrument. Record each individual test result as x_i , where i ranges from 1 to n , the total number of test results in the set. Note and record the range of operating conditions (operator, temperature, humidity, automatic recalibration, loading and unloading of the test specimen, repositioning, illumination, etc., as appropriate) encountered while the set of test results is being collected.

NOTE 6: The test specimen should have characteristics including uniformity that are typical of test specimens to be measured in practice. If evaluation of the test instrument is desired over a range of parameter values (levels), the procedure may be carried out at each level of interest.

NOTE 7: Specification of sampling plans is beyond the scope of this practice. Related Information 1 gives examples of what constitutes a test result for several different types of automated measurement instrumentation.

5.2.3 Estimate the overall standard deviation, $\hat{\sigma}$, of the test results as follows:

$$\hat{\sigma} \approx s = \left(\sum_{i=1}^n \frac{(x_i - \bar{x})^2}{n - 1} \right)^{1/2}$$

where:

s = the sample standard deviation of the set of n test results, and

$\bar{x}$ = the sample mean $\left(\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i \right)$.

5.2.4 Take as the precision, P , the quantity

$$P = 6\hat{\sigma}$$

5.2.5 Calculate the P/T ratio, in percent, as follows:

$$P/T(\%) = \frac{P}{T} \times 100$$

and round to the nearest percent.

6 Interpretation

6.1 The value against which the P/T ratio is judged depends upon the application. In general, one prefers that the value of the measurement precision, P , be much smaller than the specification range, T . A test instrument is usually deemed to be suitable for the purpose if P/T lies below 10%. If P/T is greater than 30%, the test instrument is not likely to be suitable for the purpose. Cases for which P/T lies between 10% and 30% must be judged on an individual basis, depending on the requirements being placed on the measurement system.

6.2 Evaluation of the risk of erroneously obtaining a measurement result outside the specification range is