Tolerance Calculator: A Freeware Metrology Tool

Chris Grachanen
Compaq Computer Corporation

Tolerance Calculator is a Windows™ compatible software program that calculates the tolerances for test values on equipment specifications, test uncertainty ratios (TURs), reverse TURs, accumulated uncertainties, consumer's and producer's risk — and it's FREEWARE! The author developed the program originally for department use at Compaq Computer Corporation, but has received permission from the company to distribute it as freeware.

Tolerance Calculator is a Freeware, Windows™ compatible software program that performs calculations on equipment specifications to produce two-sided tolerances — the acceptable plus and minus variance around a nominal test value. Using the program reduces computation errors and the confusion associated with equipment specmanship. Equipment specifications comprised of different tolerance components such as percent of reading, ppm of range, least significant digits (LSDs), and noise floor are easily manipulated to provide bottom line criteria for evaluating equipment performance. Tolerance components normally associated with mechanical/physical equipment such as percent hysteresis and percent span are also included in the Tolerance Calculator's specification vocabulary.

Tolerance Calculator also performs metrology related computations such as test uncertainty ratios (TURs), reverse TURs, accumulated uncertainties, consumer's and producer's risk, as well as providing help files of technical references. Tolerance Calculator is a valuable tool in the following applications:

- Formulating equipment specifications
- Creating calibration data sheets and providing means for recording, evaluating and archiving calibration results
- Performing "what if" calibration scenarios
- Determining equipment calibration suitability based on accuracy requirements
- Providing an independent means for validating tolerance computations of automated calibration systems
- Performing unit conversions and percentage-based calculations

The idea for Tolerance Calculator sprang from an advertisement I read in a quality magazine. The ad was for a dedicated, statistical process control (SPC) type handheld calculator. At the time I was heavily involved in creating, proofing and authorizing equipment calibration data sheets. It was apparent from those endeavors that the leading cause for errors associated with calibration data sheets was interpreting manufacturer's specifications and then using those specifications to create two-sided tolerances. Computations involving resolution type tolerance components such as count, digits, and floor were the most troublesome. This was especially true when resolution tolerance components were combined with measured and/or range tolerance components in a single specification.

The methodology for deriving two-sided tolerances typically involved keying in nominal values and then sequencing a handheld calculator's applicable math functions until all tolerance components were satisfied. Computed two-sided tolerances were then manually entered into a data sheet software program. This process is cumbersome, time consuming, and error prone. Since a dedicated, handheld tolerance calculator was not commercially available, a software tool was considered a viable alternative; thus the Tolerance Calculator became an "as-time-permitted/lunch-time" project.

It was decided at the onset that a total uncertainty analysis of a measurement process per the requirements of the then, recently released, ISO/TAG 4/WG 3 June 1992 *Guide To The Expression Of Uncertainty In Measurements* was beyond the scope of the Tolerance Calculator. Instead, Tolerance Calculator would focus on equipment specifications to facilitate the creation of calibration data sheets. It was further decided that it would be Windows based, provide results formats for use with other software programs, use manufacturer tolerance nomenclature, provide

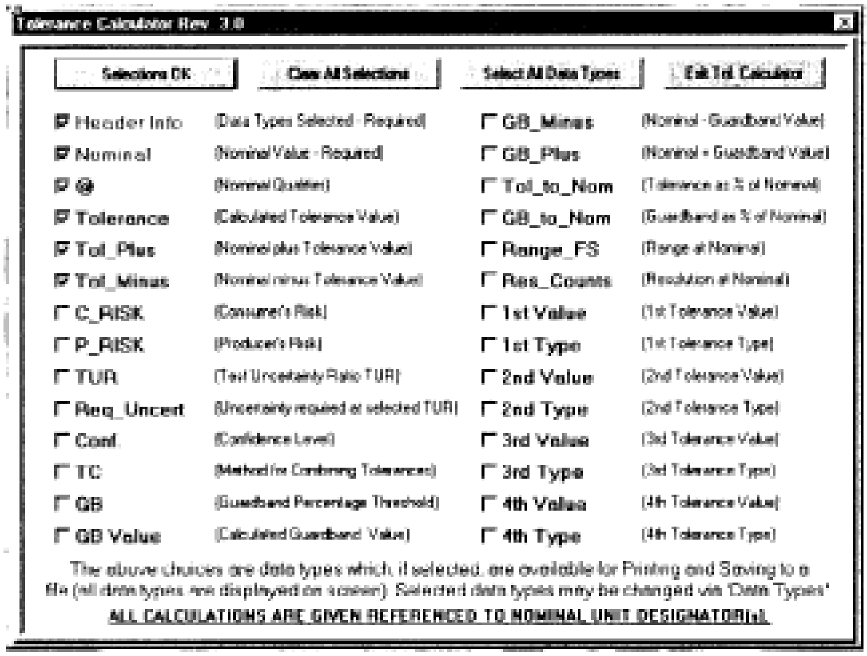

Figure 1. Tolerance Calculator data type selection screen.

data entry validation prior to computations and be user friendly.

Since its original release for internal use at Compaq Computers, Tolerance Calculator has been through four revisions and has been distributed for external use as a Freeware, public domain program.

Using Tolerance Calculator

Tolerance Calculator's compressed files (revision 3.0) fit on one 3.5", high density disk and uses 838 Kbytes. It is installed by running SETUP.EXE from Windows (3.1 or higher revision). The setup program uncompresses

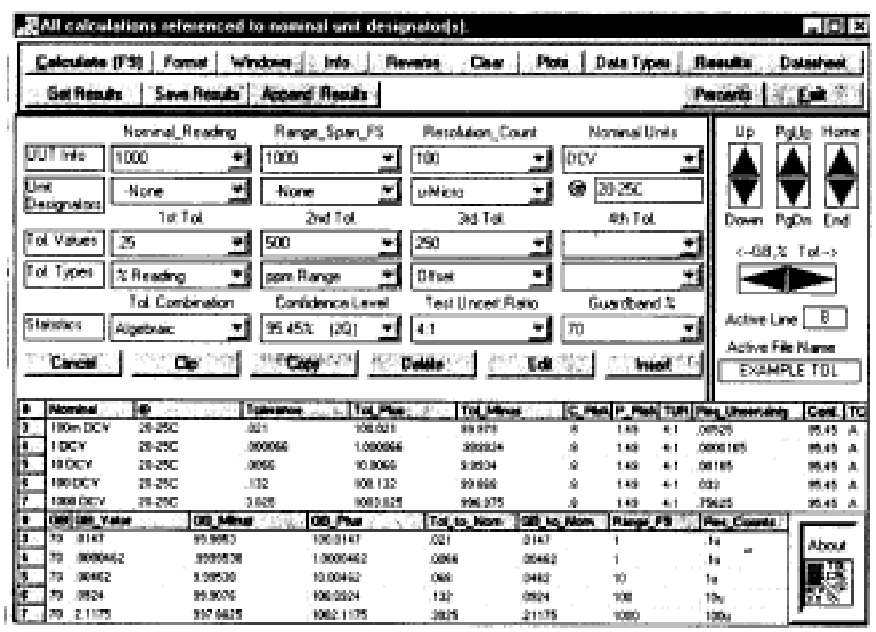

Figure 2. Tolerance Calculator main screen.

files and copies them to the Tolcal3 (default) directory automatically created by the setup program and to the Windows/System directory. An uncom-pressed Readme.txt file is included on the setup disk to assist with installation.

It is recommended after installing Tolerance Calculator that three subdirectories be manually created from its main directory: TOL (for archiving calculated tolerance results), OVR (for archiving data sheet overlays) and MEA (for archiving completed data sheets).

When opened, Tolerance Calculator displays an identification screen and then the Data Type screen (figure 1). This menu screen allows users to select the types of data that will be transferred to Windows Notepad® or Windows Write® and the save function.

The main screen (figure 2) is divided into four sections: data entry, statistics, display controls and computed results. UUT information is entered in the data entry section.

UUT nominals, ranges, resolutions and tolerance values may be keyed in using a maximum of 11 characters (0.0001 to 9999.999999) or selected from scroll down listings activated by clicking on arrow boxes adjacent to data entry fields. UUT unit designators from tera to pico (+12 to -12 exponent) for associated nominal, range and resolution values are available from scroll down listings. UUT nominal units may also be selected from a scroll down listing or entered directly (maximum of 5 characters). The "@" data entry field is a general text field with a maximum length of 8 characters.

An explanation of the mathematical models used for each tolerance type may be found in Tolerance Calculator's on-line Operator's Manual. After completing all applicable data entry fields, clicking the Calculate command button or pressing F9 will compute UUT tolerance and statistical values.

Tolerance computed results are

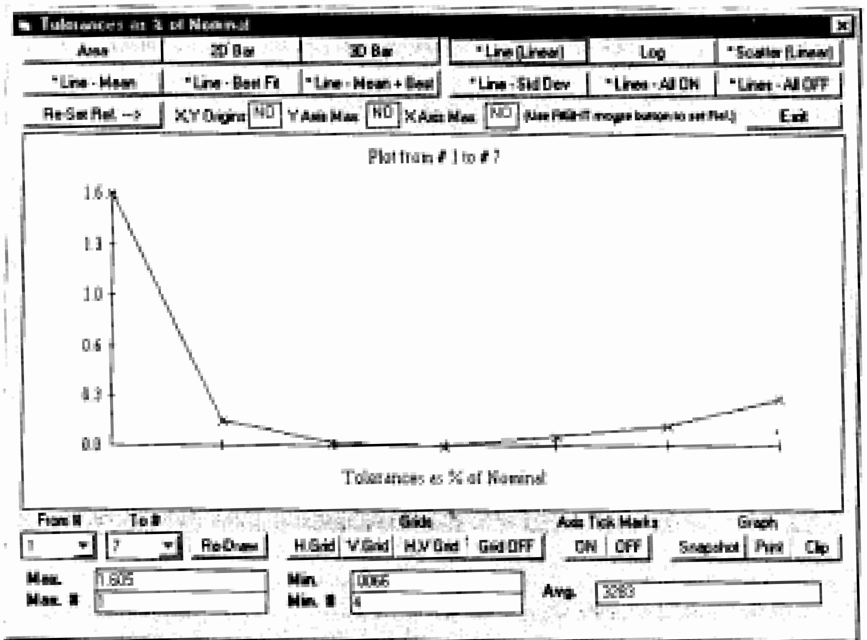

Figure 3. Linear line plot.

given relative to the nominal's unit designator e.g. 0.01% of 10 M would yield 0.001 M result. Computed results are displayed in the two spreadsheets at the bottom of the screen. The format of computed results can be customized using the Format command button and Clip, Copy, Delete, Edit and Insert commands.

The UUT statistical area is comprised of data fields for tolerance combination, confidence level, TUR and percent guardband. The tolerance combination data field determines how tolerance components are combined, either algebraically (worst case) or root sum square (RSS). The confidence level data field represents the percentage of the area of the normal curve that lies above the confidence interval. Confidence levels ranging from 68.27% (1 σ) to 99.73% (3 σ) are used in determining consumer's and producer's risk.

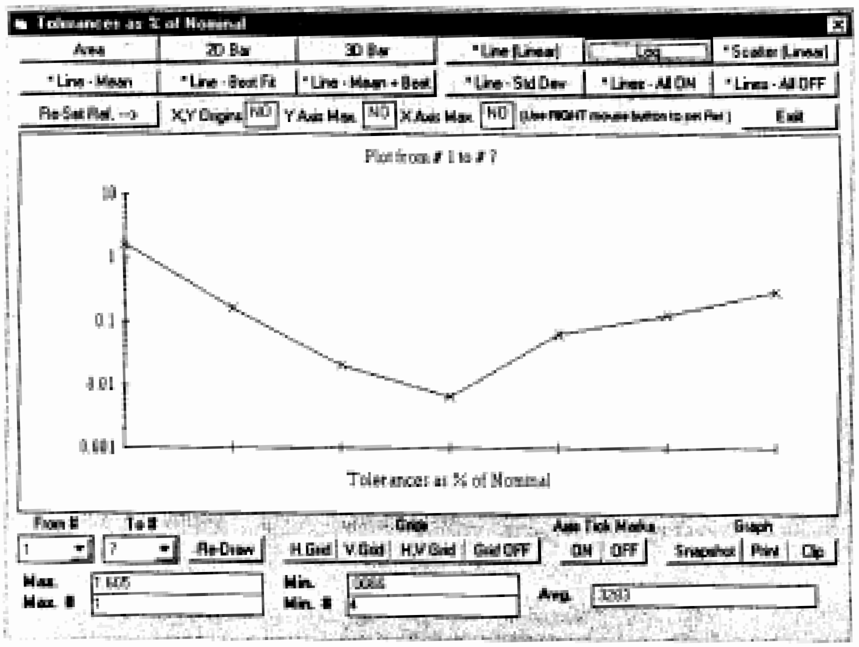

Figure 4. Logarithmic line plot.

Consumer's and producer's risks for specific confidence level and TUR combinations are derived from formulas presented in a paper titled *How To Maintain Your Confidence In a World of Declining Test Uncertainty Ratios* given by David Deaver of Fluke Corporation at the National Conference of Standards Laboratories (NCSL) 1993 Workshop and Symposium.

By changing confidence levels and TURs, different calibration scenarios can be evaluated, such as when a standard does not meet a 4:1 TUR but is at a better than 2 σ confidence level. The TUR data field can also be used for computing required uncertainties used in determining consumer's and producer's risk. TUR selections range from a ratio of 1:1 to 10:1. The percent guardband data field is a percentage, ranging from 1% to 99%, used in computing all guardband data. Defaults for UUT statistical entries are algebraic, 2 sigma, 4:1 and 70%.

Once tolerance computations have been performed, results can be plotted, printed, saved to a file, used in determining accumulated uncertainties and reverse TURs or transferred to the data sheet module of the Tolerance Calculator. Computations may be checked using the Windows Calculator command button.

Plotting computed results requires at least two result iterations. Any grouping of two or more sequentially computed results may be plotted. Line plots of tolerance values and tolerances as percentages of nominals can be displayed in linear and logarithmic fashion (figures 3 and 4.)

In addition, linear plots may be viewed in area, 2D bar, 3D bar and scatter formats. Linear line and scatter plots can display mean, best fit and standard deviation statistical lines.

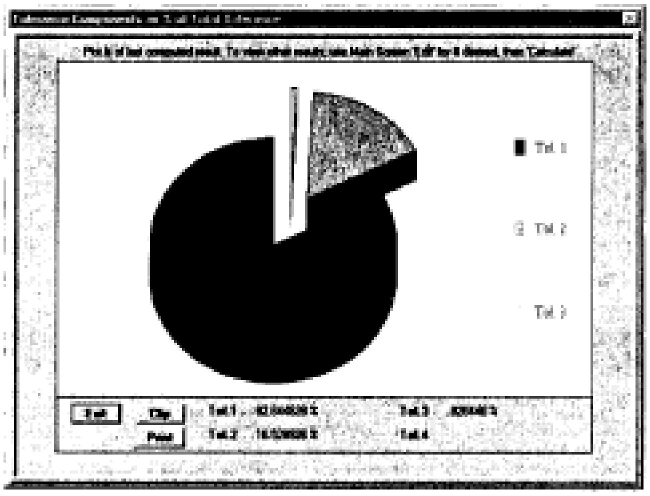

Figure 5. Tolerance components pie plot.

Linear line plots can also display plot values by right mouse clicking in sequence: the XY origin, end of the Y axis (vertical), end of X axis (horizontal); and then left mouse clicking any point on the plot. Two or more tolerance components can be plotted as percentages using a pie type format (figure 5). All plots may be clipped to Windows Clipboard for use in cut and paste activities, as well as printed. Plotting statistics are displayed for minimum, maximum and mean plot values. A snapshot listing of all plot values is displayed via the Snapshot command button.

Computed results can be saved using the default format or custom formatted for use with other software programs e.g. spreadsheet, databases. Files are saved as ASCII text. The actual data transferred to a file is dependent on the data types selected from the data type screen. The "Tol. Save" format used by the Tolerance Calculator saves computed results, row by row, using a comma data separator. Custom formats can save computed results in a row by row or column by column format using one of the following data separators: comma, space, carriage return, line feed, carriage return and line feed, colon, semicolon or no data separator.

A useful technique for saving computed results for later retrieval by the Tolerance Calculator, is to save individual equipment parameters to separate files eg. DC voltage, AC voltage, DC current. The Results Append function can be used to combine these separate files into a single file.

The Tolerance Calculator uses Windows' two built-in word processors, Notepad and Write (Writepad in Windows 95), for printing computed results. From the word processor's environments, computed results may be formatted for a specific application and then saved to a file. Of particular note is Write's ability to accept graphic objects which allows clipped plots to be pasted in it.

Computed uncertainties may be evaluated using the Tolerance Calculator's accumulative uncertainty and reverse TUR functions. The accumulative uncertainty function allows individual uncertainties components comprising a measurement system or process to be combined into a single uncertainty. Any grouping of two or more sequentially computed uncertainties may be evaluated with this function. Individual uncertainty components may be combined either algebraically (worst case) or root sum square (RSS). The total accumulative uncertainty is computed and displayed as a percentage and ppm.

The Reverse TUR function is used for comparing equipment uncertainties. This function is particularly useful for verifying stated TURs on certificates of calibration and for determining equipment suitability for use as calibration standards. Any computed uncertainty may be evaluated to any other computed uncertainty regardless of iteration sequence. Accumulative uncertainty and reverse TUR results can be transferred to Write or Notepad.

The datasheet module uses computed results to document actual calibrations. Clicking the Datasheet command button transfers computed results to the datasheet module's spreadsheets. The top spreadsheet displays numerical information while the bottom contains descriptive information (both spreadsheets are synchronized with each other for viewing purposes). The clip function can be used to transfer portions of a spreadsheet to the Windows Clipboard. The add/edit function allows editing of computed results as well as creating and adding tolerance types.

The datasheet module's header data entry fields are based on section 13.2 requirements of ISO/IEC Guide 25 (Rev. 3, 1990) *General Requirements for the Competence of Calibration and Testing Laboratories* and ANSI/NCSL Z540-1-1994, *Calibration Laboratories and Measuring and Test Equipment - General Requirements*. Once applicable header information has been completed and any additional tolerances and/or comments added, they can be saved as an overlay file for future use. Overlay files can be transferred to Write or Notepad and printed.

Calibration results may also be entered directly into a overlay file and then saved as a measurement file, providing documentation of a UUT's calibration. Entered calibration results for operator and single side band evaluations are computed on a pass/fail criteria, while entered calibration results for two-sided tolerances types are computed as percent of tolerance and percent of change (for a nominal of zero, the actual offset from zero is calculated). Computed percent of tolerance and percent of change results can be plotted. Using the clip function to paste a percent of tolerance plot into a Windows Write measurement file greatly assists in identifying out of tolerance conditions (figure 6.)

Technical References Files

Tolerance Calculator also incorporates ancillary functions which provide general technical references, unit

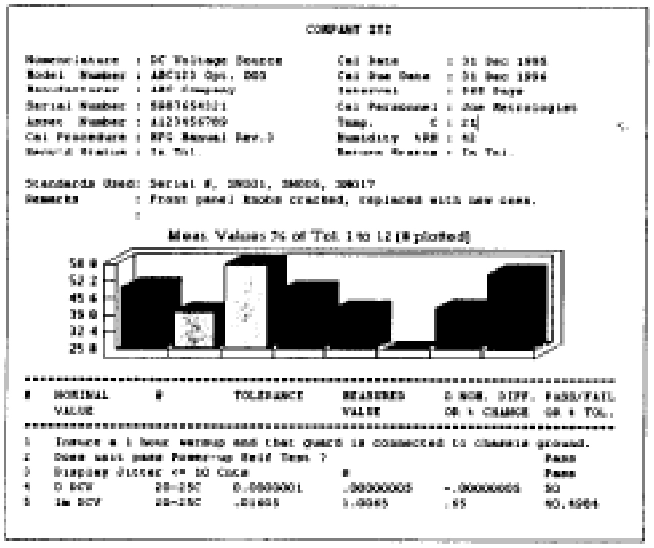

Figure 6. Completed datasheet with three dimensional plot.

conversions and percentage calculations. The technical reference and unit conversion functions are accessed using the Info command button. The technical reference section provides information under the following topics:

- International System of Units (SI) Base Units
- SI Supplemental Base Units
- SI Derived Units & Units to SI values
- SI Multiplication Factors
- Physical Constants Table
- Popular Fixed Points (ITS 90)

Technical reference topics may be transferred to Write or Notepad for viewing, printing or saving to a file. Sections may be cut and pasted directly into Windows' built-in calculator for use as numeric data. The unit conversion function provides forward and reverse conversions using SI units.

Percentage calculations can be performed using the Percent command button to obtain the following computations:

- Measured value as a percentage relative to the nominal value
- Measured values as a percentage change from the nominal value
- Measured value percentage of the nominal value e.g. percent of total

Computed results may be transferred to Write and Notepad or cut and pasted into other applications.

Obtaining Tolerance Calculator

A copy of Tolerance Calculator can be obtained free of charge from Norfox Software, Inc. Norfox is providing distribution of the Tolerance Calculator as a public service to the measurement/metrology community. A copy can also be downloaded from the Fluke Corporation Metrology bulletin board service at +1-206-356-5309.

Tolerance Calculator is already in use in metrology and calibration laboratories all over the world; its distribution propagated mostly by word of mouth. It is the author's hope that this article will give readers an insight into the Tolerance Calculator's many capabilities and encourage other software authors to donate their efforts into the freeware arena.

Chris Grachanen, Compaq Computer, P.O. Box 692000, MS 070110, Houston, TX 77269, USA. Phone: +1-713-518-8486, fax: +1-713-518-7275.

Norfox Software, Inc. 3400-188th St. SW, Suite 285, Lynwood, WA 98037 USA. Phone: +1-206-774-9118, fax: +1-206-774-9602.