BRISTOL
INSTRUMENTS

TECHNICAL NOTE - 006-M

Accuracy, Repeatability, Traceability

What do these terms really mean in thickness measurement?

INTRODUCTION

Manufacturers of precision instruments use terms like accuracy, repeatability and traceability when specifying their system performance. These terms can be confusing and are often misused by metrology companies to artificially inflate the performance of their instrumentation. Bristol Instruments strives to align our specifications with NIST's (National Institute of Standards) terminology which are internationally recognized and scientifically sound.

BRISTOL INSTRUMENTS USES NIST RECOMMENDED TERMINOLOGY

Accuracy

"Accuracy is the closeness of agreement between a measured quantity value and a true quantity value of a measurand. And it is noted that "The concept 'measurement accuracy' is not a quantity and is not given a numerical quantity value." [1]

The definition of accuracy that NIST promotes is published by the Bureau International des Poids et Mesures (BIPM) which among other duties is responsible for defining the International System (SI) of units. BIPM publishes a document governing the international vocabulary of metrology as well as a guide to the expression of uncertainty in measurement.

When accuracy is specified by a number it must be associated with an uncertainty statement which tells the customer what portion of the measurements fall within the specified range. For example, Bristol Instruments gives an accuracy specification for the 157 optical thickness gauges as an uncertainty of 100 nm with a coverage factor of 3 which provides a confidence level of greater than 99.7%. This means that for the model 157 that at least 99.7% of all measurements that are taken within the specified environmental and operational limits will be within 100 nm of the true value.

Repeatability

"Repeatability (of results of measurements) is the closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement." [2]

Bristol Instruments specifies repeatability as the standard deviation of data recorded over a 60 minute measurement period, which for the 157 is 20 nm. This specification is useful in addition to the absolute accuracy specification because it helps the user understand how stable the measurement is, not just how close it is to the true value. With a more repeatable measurement it becomes easier to discern small differences in the dimensions of different parts.

Traceability

"Traceability is the property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty." [3]

Metrological traceability is a concept that is at the heart of both NIST and BIPM and is crucial to establishing trust in measurements. It is the method used to ensure that measurements made in one lab can be reliably compared to those made in another far away lab.

NIST traceability is the slightly more specific condition of being traceable to reference standards developed and maintained by NIST. This brief definition does not address the reliability of a measurement which may be made improperly or with instruments that have changed since their last calibration.

"It is important to note that traceability is the property of the result of a measurement, not of an instrument or calibration report or laboratory. It is not achieved by following any one particular procedure or using special equipment. Merely having an instrument calibrated, even by NIST, is not enough to make the measurement result obtained from that instrument traceable to realizations of the appropriate SI unit or other specified references. The measurement system by which values and uncertainties are transferred must be clearly understood and under control." [3]

Bristol Instruments verifies the accuracy of its optical thickness gauges before shipping using gauge blocks that have been calibrated with NIST traceable measurements and corrected for temperature with a similarly calibrated thermometer. Bristol Instruments does not suggest a calibration schedule, but several decades of experience with the moving Michelson air interferometers at the heart of these instruments suggests that these systems are extremely stable. It is left to the customer to decide how often to verify the accuracy of their measurement system, which it is important to recognize includes more than just the instrument itself. The environment, operators, and most importantly measurement artifacts used for verifying accuracy are all important to assuring measurement fidelity.

BRISTOL INSTRUMENTS HAS A PROCESS FOR VERIFYING ACCURACY

To verify the accuracy of Bristol Instruments' OTG measurements are made of the air gap between optical flats which have been wrung onto both sides of gauge blocks. The supplier of the gauge blocks provided measurements of their thickness with uncertainties of less than 0.080 microns and the blocks' thicknesses are corrected for temperature with a calibrated thermometer. The gauge blocks are stored and measured in a thermally insulated chamber ensure a uniform temperature and therefore the accuracy of temperature corrections to their thickness. These gauge block measurements are simply used to verify that the instrument is accurate and are not used for calibration. The models 137 and 157 are expected to be accurate as-built and the gauge block measurement is a quality assurance check before shipping. There is no adjustability in the system available to recalibrate the instrument.

BRISTOL 137 AND 157 INSTRUMENTS ARE EXPECTED TO BE ACCURATE FOR THE LIFETIME OF THE INSTRUMENT

When each instrument is built the discrete optics are epoxied in place and in our decades of collective experience with these moving Michelson interferometers we have found them to be very stable. An internal Helium Neon (HeNe) laser following a parallel path to measurement beam tracks the changing optical path difference between the fixed and moving arm of the interferometer. Although the changing temperature and pressure of air changing the air's dispersion makes it possible for error at part per million levels these fluctuations are compensated for by internal temperature and pressure sensors. The HeNe provides an extremely stable ruler against which to analyze the signal returning from the sample and has been a recognized standard of length since 1983 with a relative standard uncertainty of 1.5 ppm. In contrast, the commonly used DFB laser operating at 1550 nm operating with a 'single frequency' output has a wavelength uncertainty of ±0.5 nm which is over 200 times the relative uncertainty of the HeNe. The HeNe is a gas laser and does not rely on any stabilization electronics or locking scheme. The 1.5 ppm uncertainty is applicable regardless of the laser's age, environmental conditions and isotropic mixture.

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CONCLUSION

There is often confusion with the terminology describing the performance of thickness measurement gauges. This paper has attempted to clarify these definitions and explain that the methods used by Bristol Instruments conform to the standards identified by NIST and the Bureau International des Poids et Mesures (BIPM). This paper further explains that the Optical Thickness Gauges manufactured by Bristol Instruments are accurate as described by this terminology and include an internal reference to ensure the gauge will never need calibration.

REFERENCES

[1] *https://www.bipm.org/utils/common/documents/jcgm/JCGM_200_2008.pdf*
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[3] *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4891962/pdf/j31ehr.pdf*