UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899-

REPORT OF CALIBRATION
NIST Test No. 821/275185-07

For: (1) NIST Committee Meter Bar

Submitted by: NIST
100 Bureau Drive
Gaithersburg, MD 20899
USA

This meter bar has been measured using an error-mapped coordinate measuring machine. The CMM is housed in a constant humidity measurement environment where room temperature is controlled to 20.00 ± 0.05 º C. The measurement process employs several parts. The artifact is measured multiple times to generate short-term repeatability data and to sample artifact geometry and surface finish effects. The primary NIST step gauge control standard was measured concurrently to develop statistical long-term reproducibility data for the measurement system. The meter bar was horizontally supported at the points that result in a minimum bending condition. No restrictive or clamping devices were used. The length along an axis through the centers of the gauging surfaces is reported. The committee meter bar is identified through the stamp signifying that the bar is equivalent to 1/10,000,000 part of the quarter of the meridian.

Committee Meter of 1799 mark of Identification

The coefficient of thermal expansion (CTE) was assumed to be 11.60 ppm/º C.
The average gage temperature during the measurements was 20.008 º C.
The results are corrected to 20.000 º C.

The uncertainty of the measurements was calculated according to NIST Technical Note 1297, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," and the ISO document "Guide to the Expression of Uncertainty in Measurement". The expanded uncertainty, U, using a coverage factor of k = 2, is [± 1.39 + 0.2*L] µm (where L is in meters) for the measured central distance in the above fixturing configuration. Different fixturing configurations may result in deviations from these results. A detailed error budget is included in the following pages.

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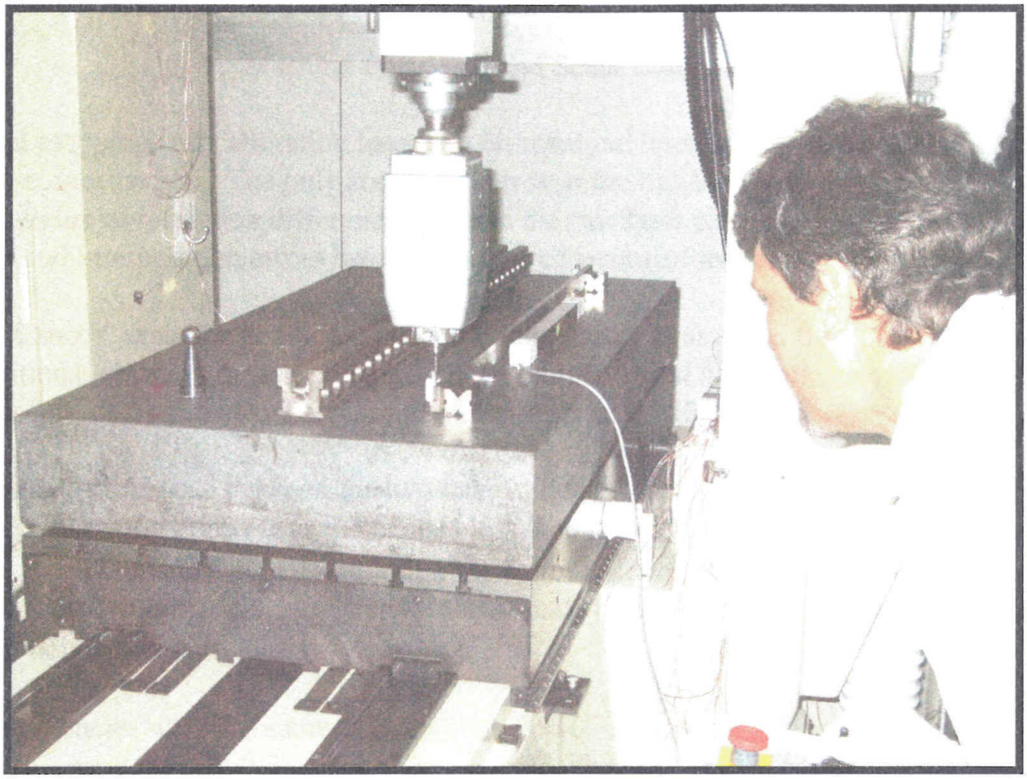

Measurement of the NIST Committee Meter using the M48 Coordinate Measuring Machine

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Measurements made by ______________________ (301) 975-3468.
John R. Stoup

For the Director,
National Institute of Standards and Technology

Dr. Theodore D. Doiron, Group Leader
Engineering Metrology Group
Precision Engineering Division
Manufacturing Engineering Laboratory

Group Control No. M9024
Date: June 11, 2007

Uncertainty budget for M48 1D & 2D Calibrations

1. Machine Positional and Scale Uncertainty

The external mapping and calibration laser and on-machine laser scales were set for the same wavelength compensation. The only sources of error in the machine map are the reproducibility of the map, index of refraction difference between the two laser paths, difference in laser frequencies and interpolation errors between measured points of the map.

Along the X and Y axes, the positional and scale uncertainty is assessed by analyzing the error map of positional errors as measured by gridplate, ballplate, and hole rotation assessments. The average standard deviation of the positional errors is about 0.040 µm.

The temperature difference between the two beams is quite small. In fact the temperature difference between any points near the table is less than 0.02 °C, giving an associated error of 0.02 µm/m. Taking this as the half width of a rectangular distribution we get a standard uncertainty of 0.01 µm/m. The atmospheric pressure difference between the two beams, 200 mm apart in height, is negligible.

The laser frequencies were the same to a few parts in 10^{-8}. We have taken 2×10^{-8} as an estimate of the standard uncertainty from this source. The error map smoothness is quite good and linear interpolation between the measured points, 25 mm apart, is indistinguishable from the map reproducibility cited above.

2. Check Standard and History Reproducibility

We have measured many gages on the same machine for over 5 years and have high quality check standard data (over 200 calibrations of 900 mm, 600 mm steel gage blocks, over 50 calibrations of a 1020mm step gauge) as well as hundreds of measurements of check standard ring and plug gages. Analysis of the check standard data show the reproducibility (1σ) level is $0.040\ \mu m + 0.040 \times 10^{-6}\ L$.

3. Wavelength Compensation

The wavelength compensation has two parts. First the current wavelength is calculated from the atmospheric pressure, temperature and humidity using stand alone monitors and loaded into the computer. During the run, the wavelength compensation is updated using internal recalculations and re-measurements of the environmental components. The sources of error are therefore: the Edlén Equation to convert pressure, temperature and humidity to wavelength correction, and the uncertainty in pressure, temperature and humidity used in the equation.

The old Edlén equation was estimated to have a systematic error of about 5×10^{-8}. The new equation based on the refractometry of air work at NPL is stated to be accurate to about 3×10^{-8}.

Since the environmental sensors have had multiple calibrations during the time span of the check standards and customer histories, the variability due to these sensors will eventually be adequately sampled in the reproducibility data. Currently, however, we have less than 10 recalibrations of the temperature, pressure, and humidity instruments that make up the weather station. The thermometer calibration history shows the thermistors "as found" condition at calibration to have a standard deviation of 0.006 ºC. Using this and the dependence of the refractive index on the temperature we get a standard length uncertainty of 6×10^{-9}. The standard uncertainty in pressure, derived from the "as found" condition on calibration over the last two years, of 10 Pa gives a length uncertainty of 3×10^{-8}, and the humidity uncertainty of 4% gives a length uncertainty of 4×10^{-8}.

4. Thermal Expansion Correction

There are two sources of uncertainty associated with thermal expansion: the uncertainty in the thermometer measurement and the uncertainty in the value of the thermal expansion coefficient. The system uses thermocouples referenced to a calibrated SPRT. The uncertainty in this system has been tested by measurements against other calibrated SPRTs. The standard uncertainty from these comparisons is estimated to be 2 mK. Multiple thermometers are placed on or in each artifact. Temperature differences along artifacts are generally under 4 mK, and corrections are applied for larger differences.

The uncertainty in the thermal expansion coefficient of the artifact depends on the artifact. For steel artifacts of unknown origins we will take the uncertainty to be 1×10^{-7} /°C. The uncertainty in the length measurement due to temperature and CTE effects is less than 2×10^{-9} /°C.

5. Contact Deformation

The contact deformation is negligible for uni-directional step gages, since the deformation is the same on each step. For bi-directional step gages a small correction for deformation must be made for gages which are not steel. Since the probe is calibrated using a steel gage block the deformation is the same for the master block and step gage. For gages of other materials the correction is made using the formula of Puttock and Thwaite (CSIRO Report, 1967). The deformation of a plane-sphere contact has been calculated independently at NIST, and checked experimentally. No statistically significant differences have been found between experiment and theoretical results. Because of the very low force used by the probe the corrections are small, making the uncertainties almost negligible. We estimate that the corrections for this geometry have an uncertainty of less than 0.002 µm.

6. Artifact Geometry (alignment and gaging surfaces)

The parallelism and flatness of the gaging surfaces and the quality of the gage references can affect the quality of the calibration. These effects are considered for each customer gage and put in the budget as needed. Tests were run on each gaging surface to measure the variability of the length in the area around the gage point. For this meter bar the variation in length was measured to be approximately 1.2 micrometers. We estimate that our measurement points would vary from the true gage point by no more than 0.2 mm based on the techniques used for the generation of the coordinate system and the squareness of the bar itself. Using this as the as the half width of a rectangular distribution we get a standard uncertainty of 0.693 μm.

ERROR BUDGET CALCULATION

In order to present an uncertainty statement of the form (A+BL) we calculate the uncertainty for short artifacts by summing the squares of the length independent sources and take the square root to be (A). We then sum all of the sources using L as 1 meter and take the square root to be (A+B) and solve for B. This procedure overestimates the uncertainty for the intermediate lengths slightly, but is necessary if we are to have a linear uncertainty statement.

1D & 2D ARTIFACT UNCERTAINTY BUDGET

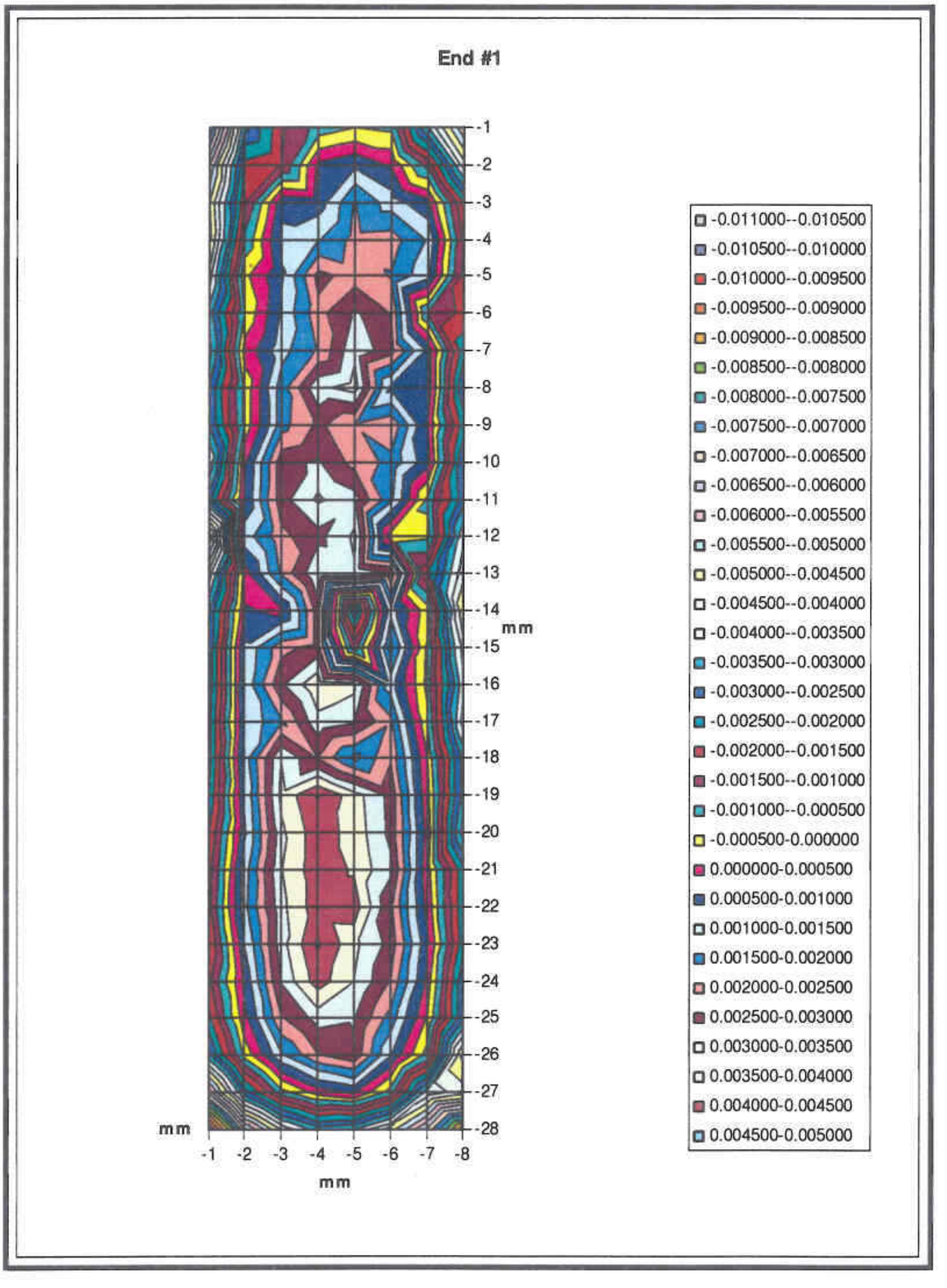
Source	µm	ppm
Machine Scale Uncertainty	0.04	
Temperature difference in beam paths during calibration		0.01
Laser Frequency Difference		0.02
Measurement Reproducibility	0.04	0.04
Edlén Equation		0.03
Index of Refraction – Air Temperature		0.01
Index of Refraction - Air Pressure		0.04
Index of Refraction – Humidity		0.03
Thermal Expansion		0.05
Coefficient of Thermal Expansion		0.05
Contact Deformation	0.002	
Gage Surface Geometry	0.693	

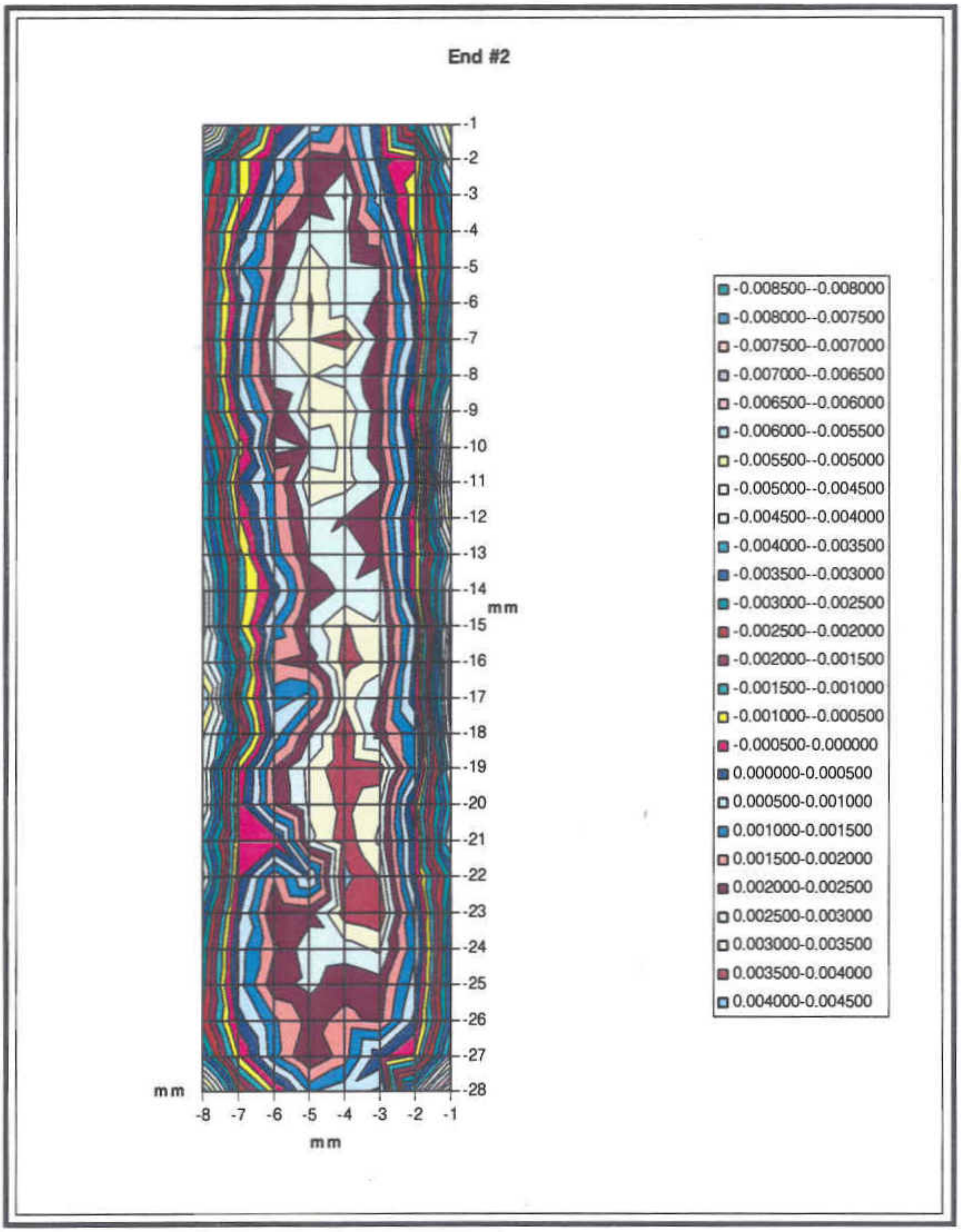
Where L = 1 meter

U_{tot} (µm) = 1.39 µm + 0.20 x 10^{-6} L (k = 2)

Nominal Length (mm)	Measured Length (mm)	Expanded Uncertainty (k=2) (mm)
1000	1000.233 56	0.001 59

**** Data was also collected in a 1mm x 1mm grid formation on each gauging surface to examine the surface geometry. These surface maps are included below.**

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mm
mm
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-1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -24 -25 -26 -27 -28
-0.008500--0.008000
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-0.007500--0.007000
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