Length Metrology of Complimentary Small Plastic Rulers

by

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INTRODUCTION

The national measurement system concerns the relationships between individual measurements and the specific units of measure. In some cases, gage blocks for example, there are standards, a large body of scientific research, and considerable effort taken to trace the accuracy of blocks used in manufacturing back to the unit of length. The international trend to laboratory accreditation (NVLAP, NAMAS, etc.) is a formalization of the idea of assuring measurement accuracy by assessment of laboratory practice and evaluation of a measurement system's relation to the unit of length.

There are, however, a number of very important measurement systems which have, through gross negligence of the measurement community, been systematically ignored. An outstanding example of this neglect is the small plastic ruler (SPR). While CAD systems are slowly making some inroads into the use of SPRs, there are virtually no active scientists or engineers who do not have a number of SPRs in their desks which are used continually for developing the earliest and most basic designs of virtually every object manufactured. A quick survey of engineers will show that these early sketches, the very basis of our manufacturing economy, are largely dependent on the use of SPRs. While there is a federal standard for plastic rulers, Federal Specification GG-R-001200-1967 and the newer A-A-563 (1981), there has never been a systematic study of the metrology of this basic tool of the national measurement system.

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This study is the first systematic study of SPRs. A complete study of all SPRs is beyond the scope of even a large national laboratory. We have found, however, that engineers in private industry, being acutely aware of economic factors, primarily use SPRs obtained for free at conferences and equipment shows. We have, therefore, focused our study on these complimentary small plastic rulers (CSPR). As an interesting sidelight, while these rulers are plentiful in industry, we were unable to obtain any samples from our contacts at the Department of Energy, Department of Defense or NASA. We have suggested to university colleagues that a study on the relation between CSPR use and efficiency and cost effective engineering design might be an interesting topic for a graduate thesis. It is, unfortunately, beyond the scope of this study.

PROCEDURE

The 50 CSPRs measured in this study were collected over a long period of time at conferences and from colleagues. We have limited our study of the primary steps on each scale: {0, 1, 2, 3, 4, 5, 6} inches for inch scales and {0, 25, 50, 75, 100, 125, 150} millimeters on the metric scales.

The CSPRs were measured on a traveling microscope which uses a precision lead screw as the scale. The lead screw was calibrated with a chrome on glass 150mm precision scale calibrated on the NIST linescale interferometer[1234] - the nations primary link to the defined meter - with an uncertainty of approximately 0.05 µm for the 150 mm scale. In order to maintain as short a traceability trail as possible our micrometer was set up approximately 4 meters west of the linescale interferometer. The micrometer scale was found to be within 0.010 millimeters of the nominal readings. Since this was of the same order of magnitude as the reproducibility found in the capability study we did not develop an error map for the system, but used the readings without correction.
A standard reproducibility test was run. It consisted of repeated measurements of two CSPRs by both authors and other staff members.[5] Samples of these runs are shown in

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[1]Beers, John S., "Length Scale Measurement Procedures at the National Bureau of Standards," NBSIR 87-3625, 1987.

[2]Beers, J.S. and K. Lee, "Interferometric Measurements of Length Scales at the National Bureau of Standards," Precision Engineering, Vol.4, No. 4, 1982.

[3]Page, B.L., Calibration of Meter Line Standards of Length at the National Bureau of Standards," Journal of Research of the National Bureau of Standards, Vol. 54/1, 1955.

[4]Judson, L.V. and Page, B.L., "Calibration of the Line Standards of Length of the National Bureau of Standards," Journal of Research of the National Bureau of Standards, December, 1934.

[5] The authors would like to thank Miss Kelly Warfield and Mr. Seth Merrit for their cooperation on these tests.

figure 1. The standard deviation found between these readings was 8 micrometers. The master scale used to calibrate the instrument, therefore allowed us to maintain a more than reasonable accuracy ratio of approximately 200:1 for the measurements.

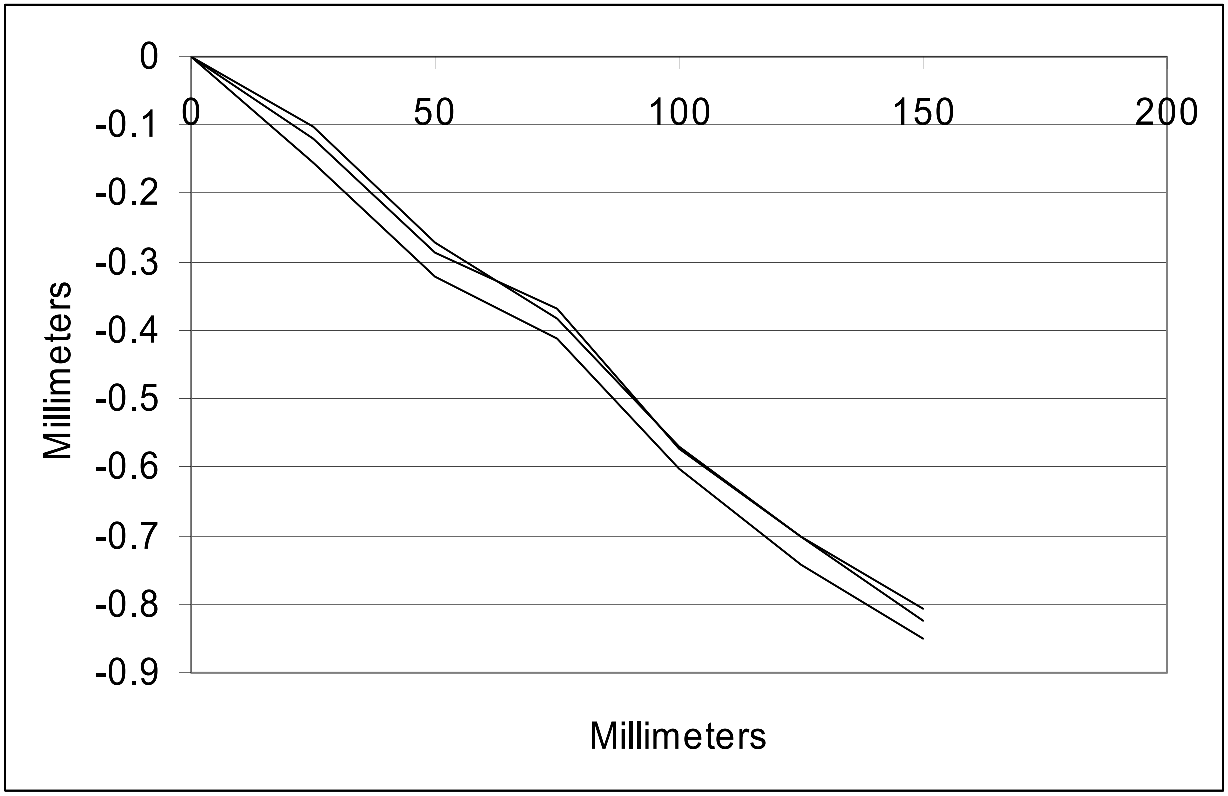

Figure 1. Examples of CSPR calibrations made during capability studies by two different experimenters.

During the capability study we found that the measurement reproducibility depended greatly on the procedure for finding the center of the CSPR lines. Four different methods were tried:

1. Centering one reticle line in the center of the scale line,

2. Setting one reticle line on each edge of the line and taking the average of the two positions as the line center,

3. Setting the line between a pair of reticle lines which were slightly wider than the CSPR line, and

4. Setting each edge of the CSPR line between a double reticle line and taking the average of the two positions as the line center.

The reason for these experiments is that many of the CSPR lines are of poor quality. The worst have lines made up of individual dots of pigment which become less dense away from the line center, but have no distinct boundary. It was found that method one produced reproducibility of over 40 micrometers, methods 2 and three were somewhat better, and method four was the best at 8 micrometers. This method was invented specifically for this study and a literature search did not find any previous recorded uses. We hope to follow up this discovery with a thorough study of setting methods for very fuzzy data. All of the data presented in this paper was taken with method 4.

Finally, the micrometer is situated in a 20EC (±0.1EC) temperature controlled room. The temperature of the micrometer was monitored with a thermistor based digital thermometer calibrated to ±0.01EC. Since the temperature of the CSPRs was maintained within 0.2EC of 20EC the thermal corrections were found to be considerably below the reproducibility of the measurement, and were ignored.

THE STANDARD

In analyzing the CSPR measurements we have the well known Federal Standards GG-R-001200 (1967) and A-A-563 (1981)," Ruler, Plastic, Desk" as a guide. In both standards we find:

> 3.3.3 Accuracy of graduations. Graduations on both scales shall be accurate to within 1/64 inch. The total accumulated error, for each scale, shall not exceed 1/16 inch.

Unfortunately, we cannot figure out what this statement means. The first phrase could mean that the 1/64 inch tolerance is to be met by the distance between adjacent marks, between the first and any other mark, or between any two marks. The second phrase is equally ambiguous. We will analyze the data according to two possible interpretations; that the distance between any two marks be within 1/64 inch of nominal and that the distance between the first and last mark be within 1/32 inch of nominal. The 1/16 inch tolerance has been halved because the standard is for 300 mm or 12 inch rulers.

Since there has been some recent controversy about the relative merits of 20EC and 23EC as the reference temperature for dimensional measurements, it is interesting to note the following paragraph from GG-R-001200:

> 4.4.1 Conditioning of test specimens. Test specimens shall be conditioned in an atmosphere maintained at a temperature of 23E±1.1EC. (73.5 ± 2EF.) and 50 ± 4 percent relative humidity for 24 hours.

Plastic rulers are one of the very few dimensional artifacts defined at 23EC, other than the PGA golf ball gage[6]. The prescience of this document is remarkable since it

[6] The United States Golf Association and The Royal and Ancient Golf Club of St.

includes a precursor to the 20-23E debate and uses metric units as primary with English units secondary nearly 25 years early.

Unfortunately, this paragraph has been completely omitted from A-A-563, leaving no environmental conditions on the testing. The omission of such a critical part of the standard is remarkable and points to the general lack of awareness of the importance of CSPRs to American Industry.

RESULTS

Figure 2 shows the results of measurements of the 30 rulers in the study. The solid lines represent the deviations from nominal of the inch scales, the dashed line the metric scales.

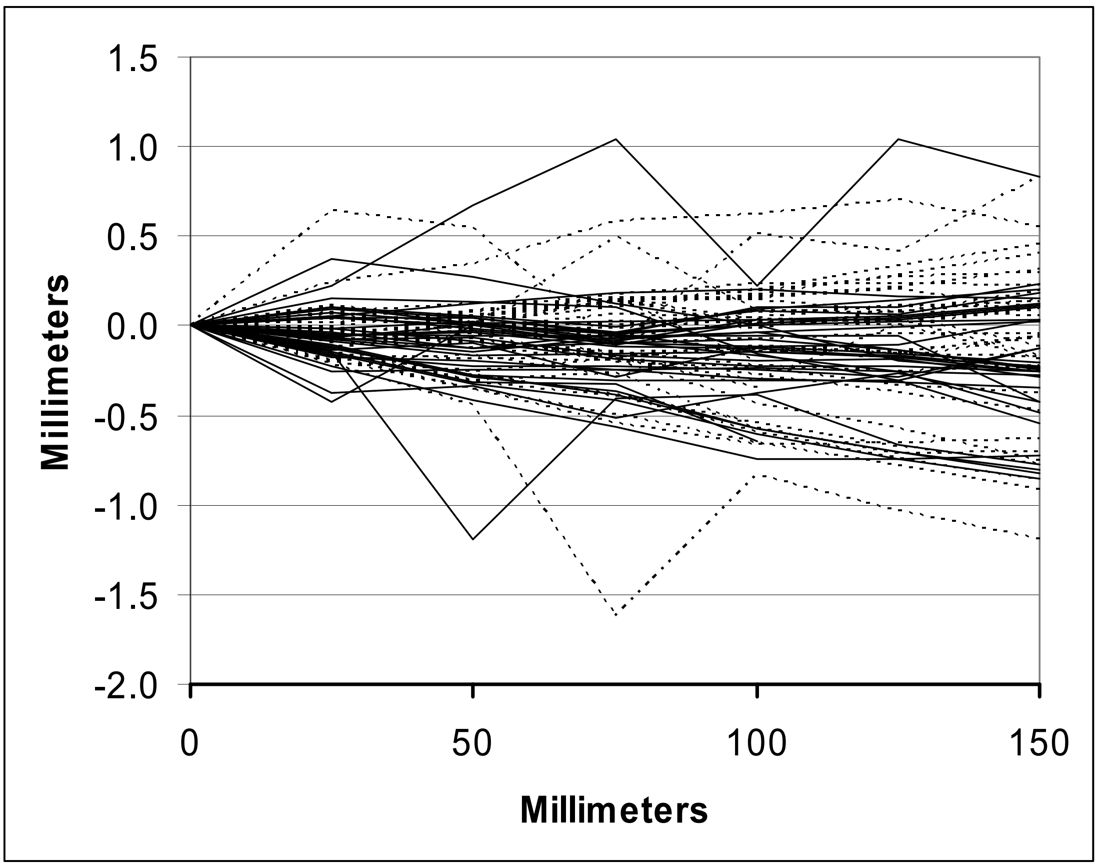

Figure 2. Data for all rulers: the solid line is the English scale and the dashed line the metric scale.

Andrews, Scotland, "The Rules of Golf", January 1, 1988.

Most of the CSPRs meet both the tolerances, and nearly all meet the second tolerance (0.8 mm , 1/32 inch) standard quite easily. Note particularly the Stratton Ruler, marked "S" in the figure. The accuracy of this CSCR is striking.

While Figure 2 is self evident, we have provided an alternative analysis of the data for those who are familiar with Youden Plots. In figure 3 we have plotted the worst case errors of each ruler, the worst error on the English scale as the X coordinate and the Metric scale as the Y coordinate. The two tolerances are shown as circles.

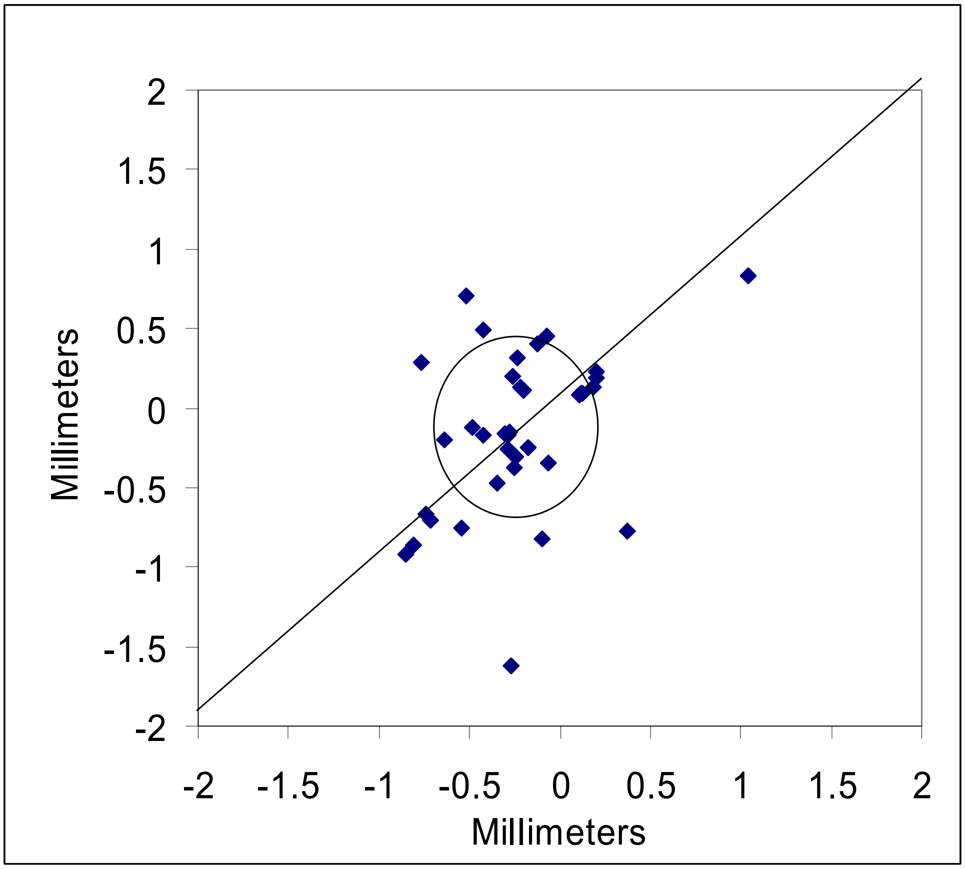

Figure 3. Plot of worst case errors for each scale. The horizontal axis is the English scale error and the vertical axis the metric scale error.

The general trend, other than the Stratton Ruler, is that the rulers supplied by private industry fall near the center of the circles and those from government do not. The rules inside the smaller tolerance were from:

Bookkeeping Agency	1
Insurance Company	1
Electronics Mfgr.	2
Mechanical Components Mfgr	2
Gaging Equip. Mfgr	1
NBS "For Good Measure"	5
NBS "Stratton Ruler"	1

One disturbing correlation in the data which is not evident from the plots is that the older the ruler the more likely it is to fall inside the circle. This trend is also seen in NIST/NBS rulers, where the older "For Good Measure" rulers are more accurate than the new models. There is a misconception that this lower accuracy has recognized by NIST since many of their CSPRs carry the phrase, "NOTE: Scales on reverse side are approximate". However, this note was on all of the earlier "For Good Measure" rulers so the note should not be taken in its colloquial sense that the scale is mediocre. It is simply a gentle reminder that since the change in the definition of the meter in 1960 all scales are approximate.

RECOMMENDATIONS

While most of the scales measured were at least adequate, the trend towards lower scale accuracy will soon endanger the use of the CSPR, and thus have a negative impact on the nation's metrology capabilities. The Federal Standard, by having an ambiguous accuracy tolerance and the unfortunate omission of the environmental specification for testing rulers may have contributed to this trend. We recommend that the ASME, through their B89.1 Committee on Length address this problem.

Another severe problem is the gradual disappearance of industry supplied CSPRs. This trend has occurred contemporaneously with the current recession, and due to the integral part of CSPRs in the manufacturing economy some study should be made to clarify the causal relation between the CSPR shortage and the recession. While NIST has made heroic efforts to fill the gap left by this trend, it is not clear that the Federal Government has the resources to completely satisfy the CSPR demand while maintaining the high quality traditionally supplied by NIST. We call on industry to awaken to this metrology problem before it becomes a crisis.