SOP No. 10

Recommended Standard Operations Procedure

for

Calibration of Rigid Rules

1. Introduction

1.1. This SOP describes the procedure to be followed for the calibration of rigid rules by comparison with the 18-inch metal rule issued to each State as the State primary standard. The interval from 1 inch to 13 inches is calibrated. It is assumed that the rigid rules have the same coefficient of expansion.

The maximum length of rule that can be directly compared to the standard rule is 12 inches. However, longer lengths can be calibrated in segments of 12 inches with reference to the standard rule.

The accuracy of calibration of standard rules is within 0.0001 inch. The precision of intercomparison and the accuracy of the standard limit the uncertainty of calibration to 0.002 inch under optimum conditions.

1.2. Prerequisites

1.2.1. The calibration certificate of the primary standard must be available and referenced.

1.2.2. The technician should be expert in making length measurements and particularly in estimating scale differences, using a reticle eyepiece.

2. Methodology

2.1. Summary

A rigid rule (test rule) is calibrated by comparing intervals on it with intervals of the standard rule. A reticle eye piece (ocular micrometer) is used for this purpose. Test rules longer than the standard rule may be calibrated in segments, using the last calibrated graduation as the zero graduation mark for the succeeding segments.

2.2. Equipment/Apparatus

2.2.1. Length bench or similar flat surface on which to lay the test rule and the standard rule.

2.2.2. Standard rule with valid calibration certificate.

2.2.3. Microscope with reticle eye piece to compare graduations. The reticle should have graduation intervals of 0.002 inch or less.

2.3. Procedure

2.3.1. Both the test rule and the standard rule must be in temperature equilibrium with the length laboratory.

2.3.2. Place the test rule and the standard rule on the length bench or similar flat surface, parallel to one another with the reading edges adjacent. It is not necessary to have the "zero" graduations in coincidence.

Ordinarily, this will require that one rule reads left-to-right (increasing units) while the other reads right-to-left (decreasing units). In this case, for convenience of calculation, the standard rule is placed in the right-to-left position. A worksheet to reverse the calibration on the standard rule is provided at the end of this SOP. Place shims under one of the rules as necessary so that the upper surfaces of both are in the same plane.

2.3.3. Place the ocular micrometer on the bench in the vicinity of the zero position and align it so that its scale is parallel to the scales under test. (See GMP No. 2 on "Reading the Center of Graduations when Using a Microscope" for instructions on how to make readings.) All observations should be recorded on a suitable data sheet such as the one included in the Appendix.

2.3.3.1. Observe and record readings of left and right sides of the corresponding graduation of the standard rule. The average of these readings will give a value for A.

2.3.3.2. Observe and record readings of the left and right sides of the corresponding graduation of the test rule. The average of these readings will give a value for B. If the "zero" graduation is the end of the rule, only the reading for the end of the rule is taken.

2.3.4. Move the ocular microscope successively to each graduation that needs to be calibrated and record readings similarly as in 2.3.3.1 and 2.3.3.2. The readings of the standard will be recorded as values for C and readings for the test rule will be for D. Caution: Be sure that the rules are not disturbed by movement of the microscope.

4.1.1. If control charts are not maintained, the standard deviation may be estimated from the average range, $\bar{R}$, of the ranges, R (absolute differences of the measured corrections) for the n intervals. Thus,

$$\bar{R} = \frac{\Sigma R}{n}$$

and

$$s = \bar{R}/d_2^*$$

The factor d_2^* is obtained by interpolation of the values in Table 9.1. The degrees of freedom, ν, associated with s should be taken as one-half the degrees of freedom shown below the appropriate d_2^* factor in the same table.†

4.1.2. If control charts are maintained and the measurement system is in a state of statistical control, the value of s on which the control limits are based may be used in the equation of 4.1. The corresponding value for ν is used when selecting the value for t.

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†Degrees of freedom are reduced approximately by the factor one-half because the same zero interval measurements are used for each interval estimate. Values should be rounded to the nearest whole number.

2.3.5. Return ocular microscope to the zero graduation and repeat readings. Accept all previous data if present zero reading does not disagree with previous reading by more than 0.002 inch; otherwise, discard and repeat entire sequence of readings until a satisfactory set is obtained.

2.3.6. Make a second set of measurements as directed in 2.3.3., 2.3.4., and 2.3.5.

3. Calculations

3.1. Calculate the center of each graduation (the mean of the left and right edges of each graduation) at each interval measured. Record each value in the appropriate space of the data sheet (See the appendix of this SOP). The center of the "zero" graduation on the standard rule is A; for the test rule it is B. The centers of graduations for the standard and the test rule are recorded as C and D, respectively, for each interval measured. For each trial the values for A and B are used to compute the measured difference between the standard and the test rule for each interval measured in that trial.

3.2. Calculate the measured differences, d_1 and d_2, for each trial for each interval measured and record on the data sheet. The measured difference $d_i = A_i - B_i - C_i + D_i$ for each trial where i is the trial number 1 or 2.

3.3. Calculate the range, R, in the measured differences as $R = |d_1 - d_2|$ for each interval and record on the data sheet.

3.4. Record the length of the standard, L_s, for each interval measured.

3.5. Calculate the length, L_x, of the test rule for each interval measured using the mean of the measured differences, $L_x = (d_1 + d_2)/2 + L_s$. Record the values for L_x on the data sheet.

4. Assignment of Uncertainty

4.1. The uncertainty, U_C, of a correction (the mean of two measurements) is given by the expression

$$U_C = \pm \left[U_s + \frac{ts}{\sqrt{2}} \right]$$

where U_s is the uncertainty assigned for the correction for the standard and s represents the estimate of the standard deviation of a single measurement. The value for t corresponding to a probability level of 99.73% and the number of degrees of freedom on which s is based will be found in Table 9.3.

Worksheet to Reverse the Calibration of the Rigid Rule Standard

To reverse the calibration on the State standard rigid rule, subract the lengths for each calibrated interval from the length from the 1-inch to the 13-inch graduation.

Example:

Length from 13 to 12 = Length from 1 to 13 - length from 1 to 12

Length from 13 to 12 = 11.9998 - 10.9997 = 1.0001 inch

Notation:

L_i = length of interval i

C_j = calibrated length of the standard from the 1-inch graduation to graduation j

C_{13} = calibrated length of the standard from the 1-inch graduation to the 13-inch graduation

Nominal Length Of Interval (inches)	Calculation To Be Performed	Length of Interval (inches)
1	$L_1 = C_{13} - C_{12} =$ _____ - _____	= _____
2	$L_2 = C_{13} - C_{11} =$ _____ - _____	= _____
3	$L_3 = C_{13} - C_{10} =$ _____ - _____	= _____
4	$L_4 = C_{13} - C_9 =$ _____ - _____	= _____
5	$L_5 = C_{13} - C_8 =$ _____ - _____	= _____
6	$L_6 = C_{13} - C_7 =$ _____ - _____	= _____
7	$L_7 = C_{13} - C_6 =$ _____ - _____	= _____
8	$L_8 = C_{13} - C_5 =$ _____ - _____	= _____
9	$L_9 = C_{13} - C_4 =$ _____ - _____	= _____
10	$L_{10} = C_{13} - C_3 =$ _____ - _____	= _____
11	$L_{11} = C_{13} - C_2 =$ _____ - _____	= _____
12	$L_{12} = C_{13} - C_1 =$ _____ - 0	= _____

Appendix

Rigid Rule Calilbration Data Sheet

Test No.: _____ Date: _____
Item Identification: _____
Standard Identification: _____
Temperature: _____ Observer: _____

		Trial 1			Trial 2		
Rule	Grad.	Left	Right	Center of Graduation	Left	Right	Center of Graduation
S	____	____	____	A = ____	____	____	A = ____
X	____	____	____	B = ____	____	____	B = ____
S_1	____	____	____	C_1= ____	____	____	C_1= ____
X_1	____	____	____	D_1= ____	____	____	D_1= ____

d_1 = A-B-C+D = _____ d_2 = A-B-C+D = _____

Range = $|d_1 - d_2|$ = _____ L_s = _____

Length of X, $L_x = (d_1+d_2)/2 + L_s$ = _____

S_2	____	____	____	C_2= ____	____	____	C_2= ____
X_2	____	____	____	D_2= ____	____	____	D_2= ____

d_1 = A-B-C+D = _____ d_2 = A-B-C+D = _____

Range = $|d_1 - d_2|$ = _____ L_s = _____

Length of X, $L_x = (d_1+d_2)/2 + L_s$ = _____

S_3	____	____	____	C_3= ____	____	____	C_3= ____
X_3	____	____	____	D_3= ____	____	____	D_3= ____

d_1 = A-B-C+D = _____ d_2 = A-B-C+D = _____

Range = $|d_1 - d_2|$ = _____ L_s = _____

Length of X, $L_x = (d_1+d_2)/2 + L_s$ = _____

S_4	____	____	____	C_4= ____	____	____	C_4= ____
X_4	____	____	____	D_4= ____	____	____	D_4= ____

d_1 = A-B-C+D = _____ d_2 = A-B-C+D = _____

Range = $|d_1 - d_2|$ = _____ L_s = _____

Length of X, $L_x = (d_1+d_2)/2 + L_s$ = _____

S_5	____	____	____	C_5= ____	____	____	C_5= ____
X_5	____	____	____	D_5= ____	____	____	D_5= ____

d_1 = A-B-C+D = _____ d_2 = A-B-C+D = _____

Range = $|d_1 - d_2|$ = _____ L_s = _____

Length of X, $L_x = (d_1+d_2)/2 + L_s$ = _____

Worksheet to Reverse the Calibration of the Rigid Rule Standard

To reverse the calibration on the State standard rigid rule, subract the lengths for each calibrated interval from the length from the 1-inch to the 13-inch graduation.

Example:

Length from 13 to 12 = Length from 1 to 13 - length from 1 to 12

Length from 13 to 12 = 11.9998 - 10.9997 = 1.0001 inch

Notation:

L_i = length of interval i

C_j = calibrated length of the standard from the 1-inch graduation to graduation j

C_{13} = calibrated length of the standard from the 1-inch graduation to the 13-inch graduation

Nominal Length Of Interval (inches)	Calculation To Be Performed	Length of Interval (inches)
1	$L_1 = C_{13} - C_{12} =$ 11.9998 - 10.9995 =	1.0003
2	$L_2 = C_{13} - C_{11} =$ 11.9998 - 9.9984 =	2.0014
3	$L_3 = C_{13} - C_{10} =$ 11.9998 - 8.9989 =	3.0009
4	$L_4 = C_{13} - C_9 =$ 11.9998 - 7.9991 =	4.0007
5	$L_5 = C_{13} - C_8 =$ 11.9998 - 6.9992 =	5.0006
6	$L_6 = C_{13} - C_7 =$ 11.9998 - 5.9995 =	6.0003
7	$L_7 = C_{13} - C_6 =$ 11.9998 - 4.9995 =	7.0003
8	$L_8 = C_{13} - C_5 =$ 11.9998 - 3.9992 =	8.0006
9	$L_9 = C_{13} - C_4 =$ 11.9998 - 2.9993 =	9.0005
10	$L_{10} = C_{13} - C_3 =$ 11.9998 - 1.9995 =	10.0003
11	$L_{11} = C_{13} - C_2 =$ 11.9998 - 0.9998 =	11.0000
12	$L_{12} = C_{13} - C_1 =$ 11.9998 - 0 =	11.9998

Appendix

Rigid Rule Calilbration Data Sheet

Test No.: 141 Date: 8/27/86
Item Identification: #365 6-inch rule
Standard Identification: #5451 State Standard
Temperature: 22.4 °C Observer: HO

Rule	Grad.	Trial 1 Left	Trial 1 Right	Trial 1 Center of Graduation	Trial 2 Left	Trial 2 Right	Trial 2 Center of Graduation
S	13	.182	.186	A = .184	.208	.212	A = .210
X	0	.183	---	B = .183	.209	---	B = .209
S_1	12	.208	.212	C_1= .210	.195	.200	C_1= .1975
X_1	1	.209	.215	D_1= .212	.197	.203	D_1= .200

d_1 = A-B-C+D = 0.003" d_2 = A-B-C+D = 0.0035"

Range = $|d_1 - d_2|$ = 0.005" L_s = 1.00355"

Length of X, $L_x = (d_1+d_2)/2 + L_s$ = 1.00355"

S_2	10	.194	.198	C_2= .196	.216	.220	C_2= .218
X_2	3	.196	.202	D_2= .199	.218	.224	D_2= .221

d_1 = A-B-C+D = 0.004" d_2 = A-B-C+D = 0.004"

Range = $|d_1 - d_2|$ = 0 L_s = 3.0009"

Length of X, $L_x = (d_1+d_2)/2 + L_s$ = 3.0009"

S_3	7	.224	.229	C_3= .2265	.192	.197	C_3= .1945
X_3	6	---	.231	D_3= .231	---	.201	D_3= .201

d_1 = A-B-C+D = 0.0055" d_2 = A-B-C+D = 0.0075"

Range = $|d_1 - d_2|$ = 0.0020" L_s = 6.0003"

Length of X, $L_x = (d_1+d_2)/2 + L_s$ = 6.0068"

S_4				C_4=			C_4=
X_4				D_4=			D_4=

d_1 = A-B-C+D = _____ d_2 = A-B-C+D = _____

Range = $|d_1 - d_2|$ = _____ L_s = _____

Length of X, $L_x = (d_1+d_2)/2 + L_s$ = _____

S_5				C_5=			C_5=
X_5				D_5=			D_5=

d_1 = A-B-C+D = _____ d_2 = A-B-C+D = _____

Range = $|d_1 - d_2|$ = _____ L_s = _____

Length of X, $L_x = (d_1+d_2)/2 + L_s$ = _____