SOP 24

Standard Operating Procedure

for

Calibration of Stopwatches and Timing Devices

1 Introduction

1.1 Purpose

This procedure is used to calibrate Type I or Type II stopwatches and timing devices used by Weights and Measures officials, industrial, technical and other interests concerned with traceable time measurements.

1.1.1 Type I: These stopwatches utilize digital, electronic circuitry to measure time intervals.

1.1.2 Type II: These stopwatches utilize analog, mechanical mechanisms to measure time intervals.

1.2 Applicable References

1.2.1 NIST Handbook 44, Specifications, Tolerances, And Other Technical Requirement for Weighing and Measuring Devices, Section 5.55, Timing Devices.

1.2.2 NIST Special Publication (SP) 960-12, Stopwatch and Timer Calibrations.

1.2.3 NIST Handbook 105-5: Specifications and Tolerances for Field Standard Stopwatches.

1.2.4 NIST SP 432: NIST Time and Frequency Service.

1.3 Range and Scope

Detailed measurement ranges, standards, equipment, and uncertainties for this SOP are generally compiled in a separate document in the laboratory.

1.4 Limitations

Limitations of this method and the applicable services that can be offered can be determined by calculating an uncertainty associated with the method that will be used to provide the comparison of time to customer devices being calibrated. The expanded uncertainty with this procedure must be less than or equal to one third (≤ 1/3) of the tolerance per NIST Handbook 105-5 when used for legal metrology applications which is 0.02 %. The primary factors limiting the calibration uncertainty are related to the human reaction time, standard deviation in operation and the resolution of the stopwatch or timing devices.

1.5 Prerequisites

1.5.1 Verify that the metrologist performing the calibration is trained and proficient in performing this procedure and that his/her start/stop response time is documented and available.

1.5.2 Standard reference time signals must be available that can provide suitable traceability to the International System of Units (SI). Several options may be considered as noted in section 2.3. Suitable reference standards are maintained, with traceability to the SI, by NIST.

1.5.3 Two stopwatches or timing devices with resolution of 0.01 s or better for determining human reaction time factors.

1.5.4 No specific environmental conditions are required for this procedure. However, calibrations should be conducted under normal laboratory conditions due to the general design of timing devices and potential temperature influences both above and below standard laboratory conditions and environmental data for temperature, barometric pressure, and relative humidity should be recorded. For most stopwatches and timing devices used in weights and measures, the influence of the human reaction time in operating the device and the resolution of the device far outweigh environmental influence factors.

1.5.5 A stopwatch support stand or lanyard that will hold a spring-driven Type II stopwatch or timing device in a vertical position for a repeat calibration.

2 Methodology

2.1 Summary

This procedure uses a NIST traceable audio time signal from a telephone (not cell phone) or shortwave receiver, or a time signal from the GPS satellites as the reference standard. The unknown stopwatch or timing device is started to coincide with the respective signal or indication for the standard, allowed to run a calculated interval, and then stopped to coincide with an additional signal from the reference standard. The correction, C_{xn}, for each run is calculated.

2.2 Caution: Calibration methods do not require opening the case of the stopwatch or timing device. A stopwatch or timing device should never be disassembled to measure the time base frequency by making a direct electrical connection.

2.3 Standards with suitable traceability and resolution must be available and may include one of the following.

2.3.1 An operational shortwave receiver to receive the broadcast timing signal on one of the frequencies listed in Table 2, or;

2.3.2 A land line telephone to call one of the numbers listed in Table 2, to receive the broadcast timing signal; or

2.3.3 A GPS master clock. Verify that the GPS Master Clock is locked to GPS signals. In order for a GPS display to be used as a reference, there must be an indicator on the unit that shows whether the display is currently locked to the GPS signal, or is in "coast" mode. If the receiver is in "coast" mode, it should not be used as a calibration reference.

2.4 Symbols Used in this Procedure

Table 1. Symbols used in the procedure.

Symbol	Description
ABS	Absolute value, mathematical function
C_{xn}	Correction of the unknown stopwatch or timing device for each run
R	Amount of rollover time[a]
X	Unknown stopwatch or timing device being calibrated
Tol	Tolerance
T_{sn}	Elapsed time of the standard for each run
T_x	Observed elapsed time of the unknown stopwatch or timing device
UTC_1	Start of calibration in Coordinated Universal Time
UTC_2	End of calibration in Coordinated Universal Time

[a] The point where the elapsed time exceeds the maximum indication of time provided by the stopwatch. At the rollover point, the stopwatch automatically starts again at zero or shuts itself off. The user of the stopwatch must account for each rollover to correctly measure long elapsed times.

2.5 Preliminary Procedure

2.5.1 Ensure proper preparation and operation of the stopwatch or timing device to be calibrated. Batteries should be fresh, if applicable. The mainspring on the device must be fully wound, if applicable. The metrologist should familiarize themselves with the operation of each button (e.g., start, stop, reset) on the stopwatch or timing device. The stopwatch or timing device should be operating smoothly and freely.

2.5.2 Determine an appropriate calibration interval, e.g., 1 hour, 3 hour, 24 hour

Ensure that a suitable calibration interval is used by using a one to five ratio of the estimated uncertainty to the applicable tolerance. The calibration interval may also require assessment of the type of stopwatch or timing device being calibrated to ensure it will continue operation for the required interval and to ensure it has sufficient resolution.

2.5.2.1 Example tolerance calculation for calibration intervals.

$$\text{Tolerance: } 3\ \text{h} \times \frac{60\ \text{min}}{\text{h}} \times \frac{60\ \text{s}}{\text{min}} \times 0.02\ \% = 2.16\ \text{s truncated to } 2.1\ \text{s} \qquad \text{Eqn. (1)}$$

For this 3 hour example, the uncertainty must be less than 0.42 seconds (and a 1 s resolution device is not suitable).

2.5.2.2 Uncertainty to tolerance ratio calculation.

$$\text{Uncertainty} < \frac{2.1\ \text{s}}{5} \qquad \text{Eqn. (2)}$$

A 1 hour calibration interval will require an uncertainty of less than 0.14 seconds. The uncertainty must be less than 3.4 seconds for a 24-hour interval and a 1 s resolution device may be able to meet this requirement.

2.5.3 Establish a Traceable Time Signal

The same signal source *must* be used for both the start and stop times.

Table 2. Reference calibration sources.

Service	Location	Telephone Number	Radio Call Letters	Broadcast Frequencies
NIST	Ft. Collins, CO	(303) 499-7111	WWV	2.5 MHz 5 MHz 10 MHz 15 MHz 20 MHz
NIST	Kauai, HI	(808) 335-4363	WWVH	2.5 MHz 5 MHz 10 MHz 15 MHz
U.S. Naval Observatory (USNO)	District of Columbia	(202) 662-1401 (202) 762-1069	-----	-----
USNO	Colorado Springs, CO	(719) 567-6742	-----	-----
National Research Council (NRC)	Ottawa, Ontario, Canada	(613) 745-1576 (English) (613) 745-9426 (French)	CHU	3.33 MHz 7.850 MHz 14.67 MHz

Note: Do not use local "time & temperature" telephone services, cell phones, or a time display from a radio-controlled clock or a website as these sources are not considered traceable.

2.6 Obtain Human Response Time Bias Data

To determine the start/stop response of the metrologist, use a shortwave receiver for continuous broadcast of the timing signals (Note: a telephone can be used but there is a time limit of three minutes for each call). Hold a stopwatch in each hand and start both stopwatches simultaneously on a minute tone and then stop both simultaneously on the very next minute tone. Record the bias from the interval for each stopwatch each time a calibration is performed and add results to the laboratory response time control chart designated for that staff member. If the start time for each watch is reset, the start time, T_{x1} will be zero in as shown in the Eqn. 7. See Section 4.1 to establish repeatability data and measurement assurance data.

2.7 Measurement Procedure

2.7.1 Connect to the selected time signal (note that a telephone signal will be limited and will not continue to broadcast during the calibration interval).

2.7.2 Start the two laboratory stopwatches used for determining the metrologist start/stop time response on a minute tone and stop on the very next minute tone. Record the bias and plot on the Human Response Time control chart for that metrologist.

2.7.3 Start the unknown timer at a minute tone and record the reference UTC time as UTC_1.

2.7.4 At or after the previously determined calibration interval, connect to the time signal again if needed, then stop the unknown timer at a minute tone and record the UTC time as UTC_2

2.7.5 Calculate elapsed time of the standard for the first run, T_{s1}, using Equation 3.

2.7.6 Calculate the unknown error for the first run, C_{x1}, by comparing the elapsed time of the standard, T_{s1}, to the observed elapsed time on the unknown timer, T_x, using Equation 4. Be sure to account for any rollover, *R*, in the unknown timer.

2.7.7 Calculate and determine the tolerance status using Equation 5.

2.7.8 If the unknown timer appears to be in tolerance switch hands used to calibrate each timer and repeat steps 2.7.3 through 2.7.7 to obtain the unknown error for run two, C_{x2}. Switching hands in this step is performed to eliminate potential errors with the human response time.

2.7.9 Calculate and report the mean correction for the unknown, $\overline{C_x}$, using Equation 6.

2.7.10 NOTE: Spring driven Type II stopwatches shall be calibrated in two different orientations; horizontal (with dial face up), and vertical (with crown up). The main spring shall be fully wound before each run.

3 Calculations (Measurement Equations)

3.1 Calculate the Elapsed Time for each Run for the Standard, T_{s1} *and* T_{s2} using Eqn. 3.

$$T_{sn} = UTC_1 - UTC_2 \qquad \text{Eqn. (3)}$$

3.2 Calculate the Error for each Run for the Unknown, C_{x1} *and* C_{x2} using Eqn. 4 and add applicable Rollover, *R*.

$$C_{xn} = (T_x + R) - T_{sn} \qquad \text{Eqn. (4)}$$

3.3 Calculate and Determine the Tolerance Status for each Run where the values pass using Eqn. 5 when the absolute value of the error plus the expanded uncertainty is less than the tolerance for the elapsed time (see Section 6.1 also).

$$\text{Pass if: } \left|C_{xn} + U_x\right| \le \text{Tolerance for } T_{sn} \qquad \text{Eqn. (5)}$$

3.4 Calculate and Report the Mean Correction for the Unknown using Eqn. 6.

$$\overline{C_x} = \frac{(C_{x1} + C_{x2})}{2} \qquad \text{Eqn. (6)}$$

3.5 Calculate the observed human response time bias using Eqn. 7.

$$\text{Bias} = (T_{x2} - T_{x1}) - (UTC_2 - UTC_1) \qquad \text{Eqn. (7)}$$

4 Measurement Assurance

4.1 Determine the human response time and bias components of the measurement process by conducting the human response time assessment as described in Section 2.6 for at least 10 cycles, switching the stopwatches into opposite hands, recording data for every event. Start a control chart for the response time for each metrologist who will be conducting timing calibrations. One additional cycle will be conducted for each stopwatch measurement and plotted on the control chart for all future calibrations. It is recommended that all laboratory staff use the same two stopwatches to establish bias and ensure that any differences detected are NOT due to differences in the accuracy of the stopwatches used. The bias is calculated using Eqn. 7.

An example of the initial chart data for the stopwatch data might look like this:

- Left Bias (watch 1) Right Bias (watch 2)
- Left Bias (watch 2) Right Bias (watch 1)
- Left Bias (watch 1) Right Bias (watch 2)
- Left Bias (watch 2) Right Bias (watch 1)
- Left Bias (watch 1) Right Bias (watch 2)
- Left Bias (watch 2) Right Bias (watch 1)
- Left Bias (watch 1) Right Bias (watch 2)
- Left Bias (watch 2) Right Bias (watch 1)
- Left Bias (watch 1) Right Bias (watch 2)
- Left Bias (watch 2) Right Bias (watch 1)

4.1.1 Observed differences in reaction time between the metrologist reaction and a reference signal are used to determine a typical bias for each metrologist.

4.1.2 Two response times are used to calculate a standard deviation to be plotted on a standard deviation chart. Response standard deviations are pooled to determine an accepted standard deviation. The observed repeatability of each calibration may be compared to the accepted standard deviation using an F-test.

4.1.3 The repeatability data for the calibration is evaluated to ensure it is within acceptable limits. If the repeatability from the two runs is outside the control limits, conduct a root cause analysis or troubleshoot the source of the problems before repeating the calibration or reporting calibration results.

4.2 The measurement process may be duplicated with a suitable check standard(s) to replicate the measurement process. However, one person may not able to actuate a standard, stopwatch or timing device being calibrated, and a check standard all at the same time and will need to offset the times at the next designated signal. Duplicate calibrations may be needed to calibrate check standards. Evaluate the check standard immediately after the runs to ensure the values are in control. Suitable check standards may be used to determine values for section 4.1. Differences in variability of Type I and Type II devices and associated resolutions (or absence of differences) will need to be verified. The check standard data will incorporate repeatability, bias, and resolution influence data; therefore, the laboratory should consider what uncertainty components could be double counted resulting in overestimated uncertainties.

5 Assignment of Uncertainty

Examples of uncertainty budgets and sample data are presented in NIST SP 960-12, Tables 8, 9, 10, and 11. The uncertainty is calculated according to NISTIR 6969, SOP 29 to ensure compliance with the Guide to the Expression of Uncertainty in Measurement.

5.1 Uncertainty for the Standard, u_s

Determine the uncertainty for the standard based on the type of standard that is used for the calibration. See pages 31 and 32 in NIST SP 960-12. (This uncertainty is usually nearly negligible for telephone, radio, and GPS standards compared to the human reaction time factors.)

5.2 Uncertainty for the human reaction time repeatability, standard deviation of the process, s_p

The standard deviation of two replicate runs are tracked over time and used to determine a pooled standard deviation associated with the repeatability of the measurement process.

5.3 Uncertainty for the human reaction time bias, u_b

A comparison between the absolute time values from the standard source and the check standard(s) are used to calculate a bias for each metrologist. The bias is calculated for at least 10 runs and is treated as a rectangular distribution.

5.4 Uncertainty for the resolution of the timing device, u_r

The resolution of the instrument is treated as a rectangular distribution whether digital or analog (as analog timing devices also use discrete 1 s intervals).

Table 3. Example Uncertainty Budget Table.

Uncertainty Component Description	Symbol	Source	Typical Distribution
Uncertainty for the reference standard	u_s	NIST traceable time standard (telephone, receiver, GPS clock) NIST website (SP 960-12)	Rectangular
Standard deviation of the process, human reaction time repeatability	s_p	Laboratory assessments, pooled standard deviation	Normal
Uncertainty of the human reaction time bias	u_b	Comparison of metrologist to reference signal	Rectangular
Uncertainty of the stopwatch or timing device resolution	u_r	Resolution of the instrument	Rectangular

5.5 Calculate the combined uncertainty, u_c, and the expanded uncertainty for the unknown stopwatch or timing device, U_x, using the root sum square method described in NISTIR 6969, SOP 29 and use the appropriate effective degrees of freedom to determine a coverage factor to provide an approximate 95 % confidence interval.

5.6 Evaluate the uncertainty. Review the conformity assessment requirements in Section 6. to evaluate the adequacy of the uncertainty. A longer time interval for the calibration may be required, especially with timing devices with larger resolutions.

5.7 Report the calculated uncertainty to two significant digits according to SOP 29 and issue a suitable uncertainty statement.

6 Certificate

6.1 Report results as described in SOP No. 1, Preparation of Calibration Certificates. Report the measured time results (and the deviation of time values from the nominal time calibrated if applicable), the duration of the calibration conducted, and calculated uncertainties.

6.2 Conformity Assessment

A stopwatch is considered to be within tolerance when the absolute value of its error plus its uncertainty is less than or equal to the tolerance established in NIST Handbook 105-5. The tolerance is 0.02 % of the calibration interval with values truncated to the device resolution as needed. Provide a compliance/conformity statement on the calibration certificate if the stopwatch or timing device will be used for a weights and measures application.

6.2.1 Example tolerance evaluation for a 3-hour interval on a device with 0.01 s resolution:

$$\text{Tolerance} = 3\text{ h} \times \frac{60\text{ min}}{\text{h}} \times \frac{60\text{ s}}{\text{min}} \times 0.02\ \% = 2.16\text{ s} \qquad \text{Eqn. (8)}$$

$$C_x + U_x = 0.25\text{ s} + 0.35\text{ s} = 0.60\text{ s} \qquad \text{Eqn. (9)}$$

The value of 0.60 s is less than 2.16 s, thus is considered in tolerance.

6.2.2 Example tolerance evaluation for a 24-hour interval on a device with 1 s resolution, truncated to the nearest second:

$$\text{Tolerance} = 24\text{ h} \times \frac{60\text{ min}}{\text{h}} \times \frac{60\text{ s}}{\text{min}} \times 0.02\ \% = 17.28\text{ s, or } 17\text{ s} \qquad \text{Eqn. (10)}$$

$$C_x + U_x = 15.0\text{ s} + 3.5\text{ s} = 18.5\text{ s} \qquad \text{Eqn. (11)}$$

The value of 18.5 s is greater than 17 s thus is out of tolerance and would be rejected.

7 Acknowledgments and Validation

Inputs to this procedure were submitted with procedures from the following State laboratories: Washington, Pennsylvania, California, and New York. The original version of SOP 24 was developed by Dan Wright and reviewed by SP 960-12 authors Jeff Gust and Mike Lombardi for suitability and compliance to requirements in SP 960-12 and good measurement practices. Modifications were made in Pennsylvania, California, and New York to introduce specific standards, applications, and recording approaches used in their laboratories. Users applying methods for weights and measures must make sure to use requirements in NIST Handbook 44 as the over/under-registration limits in SP 960-12 are reversed.

Suitability and reproducibility of this procedure was successfully demonstrated through proficiency tests (PT) conducted among the following laboratories in report NAT-16-FT-M-01 (as coded by OWM) for a 3-hour calibration interval who used SOP 24 as developed or modified in their laboratories: Pennsylvania, Troemner, New Jersey, New York, Connecticut, Ohio, California, Washington, and Hawaii; the highest normalized error (E_n) among these laboratories was 0.22. All precision assessments, P_n, were acceptable. Uncertainties varied for these laboratories from 0.068 s to 0.48 s. All participant values for the 3-hour calibration were within one third of the Handbook 44 tolerance that was specified as 1.875 s (0.017 %). Note that a tolerance of 0.02 % is specified in NIST Handbook 105-5.