An Interlaboratory Stopwatch Comparison in the SIM Region

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Abstract: *Stopwatches and timers are used for an almost unlimited number of applications and are among the most common devices calibrated by metrology laboratories. In large nations, stopwatch calibrations are typically handled by lower level laboratories, such as state or private laboratories in the United States. However, in smaller nations, the national metrology institute (NMI) will often accept stopwatches for calibration against the national standard. This paper describes and presents the results of an interlaboratory stopwatch comparison that was conducted by the NMIs of the Sistema Interamericano Metrologia (SIM) region from May 2010 through February 2011. The interlaboratory comparison involved two travelling stopwatches and 13 NMIs. Despite a large variation in experience, calibration methods, and instrumentation, most of the participants obtained measurement results that agreed to within* 1×10^{6} *of the pilot laboratory.*

1. Introduction

An interlaboratory stopwatch comparison was conducted in the SIM region from May 2010 through February 2011. The informal comparison was the first of its type held in the SIM region, a large geographic area that encompasses North, Central, and South America, as well as the Caribbean islands. Its purpose was simply to compare the measurement capabilities of NMIs that offer stopwatch calibrations to their customers, to improve their methods of calibration, and to further extend the range of metrological collaboration that has recently existed between SIM time and frequency laboratories. [1]

The level of experience amongst the laboratories varied widely. Some of the participating NMIs routinely perform stopwatch calibrations, whereas others were calibrating a stopwatch for the first time. For this reason, each NMI was allowed to select their own calibration method, based on the instrumentation and experience that they had available. The only rule was that laboratories were instructed not to open the stopwatch case under any circumstances. Each participant was also responsible for providing their own estimation of measurement uncertainty, using a method consistent with those described in the ISO "Guide to the Expression of Uncertainty in Measurement." [2]

The Centro Nacional de Metrologia de Panama (CENAMEP) in Panama City, Panama was the pilot laboratory for the comparison. CENAMEP also organized the comparison, with assistance from the Instituto Costarricense de Electricidad (ICE) in Costa Rica.

The comparison was arranged by organizing the 13 participating laboratories into two groups. Each group was asked to calibrate one of two identical stopwatches, of the same manufacturer and model number, which traveled around the SIM region. Because the pilot laboratory, CENAMEP, was a member of both groups, each group had seven members. Group 1 included the NMIs of Panama, Costa Rica, Mexico, the United States, Canada, Kenya, and Trinidad and Tobago. Group 2 included the NMIs of Panama, Brazil, Uruguay, Paraguay, Peru, Argentina, and Colombia. Twelve of the 13 nations continuously compare their national standards of time and frequency to each other via the SIM Time Network (SIMTN), and thus know the relative uncertainty of their standard with respect to all of the other SIM standards. [3] Kenya, an African nation that is an associate member of SIM, was the one exception. Although they have yet to participate in the SIMTN, they enthusiastically participated in the stopwatch comparison. Table 1 lists the 13 participating laboratories and the technical contacts that performed the measurements.

Laboratory	Nation	Technical Contacts
CENAM	Mexico	J. Mauricio Lopez-Romero Francisco Jiménez
CENAMEP	Panama	Raul F. Solis Luis M. Mojica
ICE	Costa Rica	Harold Sanchez
INDECOPI	Peru	Henry Diaz Henry Positigo
INTI	Argentina	Daniel Perez Walter Adad
INTN	Paraguay	Victor Masi
KEBS	Kenya	Ahmed Ibrahim
NIST	United States	Michael A. Lombardi
NRC	Canada	Bill Hoger
ONRJ	Brazil	Ricardo José de Carvalho José Luiz M. Kronenberg
SIC	Colombia	Gustavo C. Orozco
TTBS	Trinidad & Tobago	Theodore Reddock
UTE	Uruguay	Leonardo Trigo

Table 1. The participating NMIs (listed alphabetically by acronym) and the technical contacts.

2. Schedule and Logistics of Comparison

When the original schedule for the comparison was being planned, it was decided to allow each laboratory 30 days to complete their measurement. The time required for the measurement would be very short, a few days or less; but it was known that much longer periods would be required for laboratories to receive the traveling stopwatch from the custom's department in their country, and to ship the stopwatch to the next participant in the comparison. The participating laboratories did their best to follow the agenda, but as it turned out, 30 days was insufficient in some cases, usually due to problems with delays through customs, but sometimes due to laboratory workloads. Table 2 shows the actual dates when the measurements were completed by each laboratory. CENAMEP performed the first and last measurement for each group.

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Group 1	
Laboratory	**Date of Completion**
CENAMEP	05/12/2010
ICE	06/10/2010
CENAM	06/24/2010
NIST	08/25/2010
NRC	09/07/2010
KEBS	10/18/2010
TTBS	11/23/2010
CENAMEP	02/15/2011
Group 2	
Labatory	**Date of Completion**
CENAMEP	06/01/2010
ONRJ	06/28/2010
INTN	07/28/2010
UTE	09/06/2010
INDECOPI	10/18/2010
SIC	11/05/2010
INTI	12/17/2010
CENAMEP	01/17/2011

Table 2. The completion dates for the measurements conducted at each laboratory.

In spite of the delays, the schedule was completed in much less than one year (279 days for Group 1 and 230 days for Group 2), and we felt that technical characteristics of the traveling stopwatches remained stable enough during this period to establish a valid comparison.

3. Measurand

The measurand was defined as the dimensionless frequency offset of the traveling stopwatch, which can be determined by measuring either frequency or time, due to this relationship,

$$\frac{\Delta f}{f} = \frac{\Delta t}{T}, \qquad (1)$$

where:

$\frac{\Delta f}{f}$ is the difference between the actual and nominal frequency divided by the nominal frequency, and

$\frac{\Delta t}{T}$ is the change in time divided by the duration of the measurement.

4. Traveling Stopwatches

The two stopwatches utilized as the devices under test (DUTs) were manufactured by Casio (Fig. 1), and were identical except for their color.[1] Their time base is a 32 768 Hz crystal oscillator, similar to the oscillator found in a quartz wristwatch. The display will reset after a maximum time interval of 9 hours, 59 minutes, 59.999 s, but longer intervals can be measured if the operator accounts for the elapsed number of 10 hour cycles. The manufacturer's specifications were as follows:

- Models: HS-70W-1 (white) and HS-70W-8 (black)
- Accuracy: ±30 s/month
- Battery: 3 V, type CR2032 with 5 year life expectancy
- Dimensions: 83 mm × 64 mm× 24 mm (H × W × D)
- Weight: 82 grams

Both stopwatches were purchased by CENAMEP specifically for use in this comparison, and had not been used for any previous measurements or tests. They were both calibrated at CENAMEP prior to being shipped to the first laboratory, and after they were returned by the last laboratory. They were transported inside the protective case shown in Fig. 2, surrounded by several other layers of packing material.

CENAMEP utilized a calibration method where one reading was obtained every 10 s during a 5-minute interval. The reference standard was an electronic card installed in a computer that was disciplined by 10 MHz and 1 pulse per second (pps) signals from a cesium frequency standard. The readings corresponded to the time difference between the computer display and the stopwatch. The measurement was repeated at the same time for three consecutive days. This method of calibration is listed in CENAMEP's calibration and measurement capabilities (CMCs) in the Key Comparison Database (KCDB) maintained by the Bureau International des Poids et Mesures (BIPM). [3] The CMCs for CENAMEP list an uncertainty for this method of 0.05 s ($k = 2$), for intervals ranging from 10 s to 86 400 s. At an interval of one day, this results in a dimensionless uncertainty (Hz / Hz) of 0.6×10^{-6}. The largest contributor to the uncertainty is the reaction time of the metrologist performing the calibration. Table 3 shows the results of the two CENAMEP calibrations for each device.

The frequency of the Group 1 stopwatch changed by about -0.4×10^{-6} during the 279 day interval between the

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[1] Commercial products are identified for technical completeness only. This implies no endorsement by any of the participating laboratories. Other products might be found to work equally as well or better. This paper is a partial contribution of the U. S. government, and is not subject to copyright.

Figure 1. The stopwatch used as the device under test.

Figure 2. The stopwatch in the protective case used for shipments.

	Calibration	$\Delta f / f$ (Hz / Hz, parts in 10^6)	$\Delta f / f$ (Hz)	s / day	U (k = 2) (parts in 10^6)
Group 1 Device	Initial	5.2	0.170	0.45	0.6
	Final	4.8	0.157	0.41	0.6
Group 2 Device	Initial	6.9	0.226	0.60	0.6
	Final	7.2	0.236	0.62	0.6

Table 3. Results of initial and final calibrations of the two traveling stopwatches.

Date of Calibration		
Start Date		
Stop Date		
Calibration Configuration		
Person Performing Measurement		
Standards Used		
Traceability		
Method Used		
Environment		
Maximum Temperature		
Minimum Temperature		
Maximum Relative Humidity		
Minimum Relative Humidity		
Calibration Results		
Item	**Value**	**Unit**
Time Error (e)		
Period of Calibration (T)		
Fractional Time Deviation		
Uncertainty (U, with k = 2)		

Table 4. Form for submission of measurement results.

Laboratory	Temperature Range (°C)	Humidity Range (%)	Method	Results		U (k = 2)
				Hz/Hz (parts in 10^6)	s / day	(parts in 10^6)
CENAMEP	22.0 to 23.0	51 to 63	Direct	5.2	0.45	0.6
ICE	21.0 to 25.0	30 to 70	Time base	4.6	0.40	0.07
CENAM	22.7 to 24.0	27 to 58	Direct	5.0	0.43	3.0
NIST	24.0 to 26.0	36 to 44	Time base	5.7	0.50	0.3
NRC	22.0 to 22.2	~35	Direct	4.9	0.42	0.1
KEBS	22.0 to 24.0	56 to 60	Totalize	4.1	0.35	8.8
TTBS	20.1 to 22.7	41 to 50	Totalize	0.9	0.08	16.0
CENAMEP	22.0 to 23.0	47 to 60	Direct	4.8	0.41	0.6

Table 5A. Results for Group 1.

Laboratory	Temperature Range (°C)	Humidity Range (%)	Method	Results		U (k = 2)
				Hz/Hz (parts in 10^6)	s / day	(parts in 10^6)
CENAMEP	22.0 to 23.0	55 to 65	Direct	6.9	0.60	0.6
ONRJ	23.0 to 27.0	-----	Time base	–2.8	–0.24	1.6
INTN	20.0 to 22.0	52 to 58	Direct	6.6	0.57	2.0
UTE	22.0 to 24.0	40 to 60	Time base	7.3	0.63	0.02
INDECOPI	22.9 to 23.3	41 to 43	Time base	7.3	0.63	0.007
SIC	21.0 to 22.0	50 to 52	Time base	7.0	0.60	0.03
INTI	22.0 to 24.0	40 to 50	Time base	7.2	0.62	0.009
CENAMEP	22.0 to 23.0	52 to 60	Direct	7.2	0.62	0.6

Table 5B. Results for Group 2.

initial and final calibration performed by CENAMEP. The frequency of the Group 2 stopwatch changed by a slightly smaller amount, about 0.3 × 10^{-6} during the 230 day interval between calibrations. In both cases, the change in frequency was smaller than the estimated uncertainty of the calibration. Also, note that the time error (s / day) in Table 3 was less than 1 s, or better than the manufacturer's specification (30 s per month is approximately 1 s per day).

5. Data Submission Format and Description of Calibration Methods

Participants were asked to submit their results using the form shown in Table 4. Not all participants followed the format, and some information was omitted. However, enough information was collected from each participant to establish a basis for comparison.

As previously noted, each laboratory was allowed to select their method of calibration. However, they were required to describe the method that they selected on the form shown in Table 4. The following paragraphs briefly describe the methods used by each participant. Note that the method utilized by CENAMEP was previously described in Section 4.

CENAM calibration's method involved comparing the display of the stopwatch to the clock display of a cesium frequency standard, a form of the direct comparison method. [5, 6] The stopwatch was manually started and stopped, and readings were recorded at intervals ranging from 60 s to 10 days. This same method was employed by INTN in Paraguay

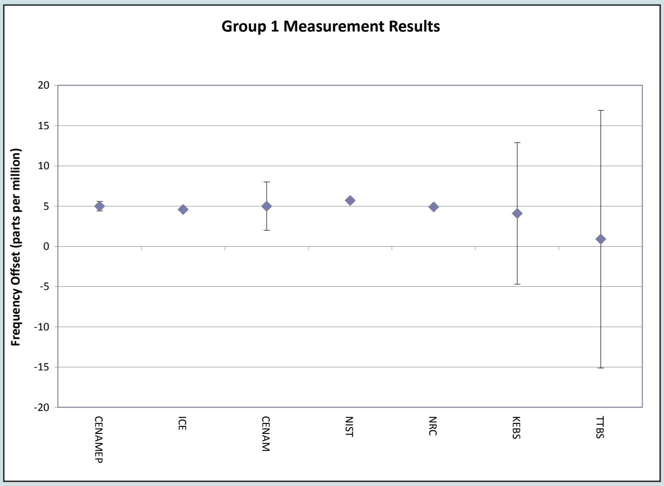

Figure 3. Group 1 results.

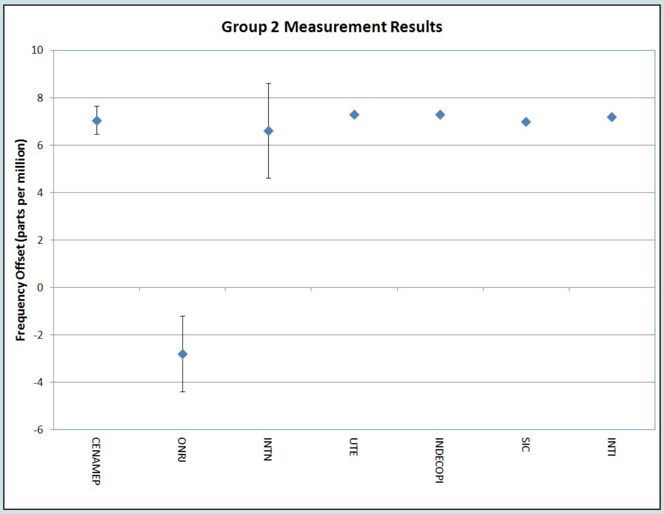

Figure 4. Group 2 results.

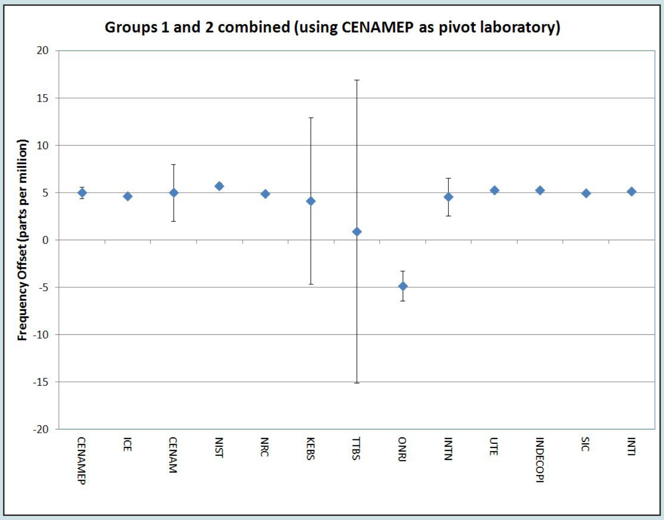

Figure 5. Results obtained by combining the two groups.

using an interval of 1 day. NRC utilized a different variation of the direct comparison method. The time base of the DUT was measured over a period of three days with respect to a cesium frequency standard. An audio signal (1 kHz tone) derived from the cesium was used as a start/stop indicator for the calibration. Three sets of measurements were taken on consecutive days. Each measurement set consisted of 16 measurements of 30 s intervals.

KEBS and TTBS both employed the totalize method [5, 7] using the totalize function of a universal counter. Both the stopwatch and the frequency counter were started manually, and multiple measurements were made of one hour intervals.

NIST implemented the time base method [5, 8] of calibration with a commercial wristwatch analyzer that can directly measure the frequency of the DUT's quartz crystal time base oscillator. This device can measure frequency with an acoustic sensor that detects the mechanical vibrations of the quartz crystal, or with a capacitive sensor that detects the crystal's stray electrical field. The capacitive sensor was used for this measurement, because the DUT has a non-conductive plastic case. The test ran for 46 hours. ICE, INDECOPI, INTI, SIC, and UTE employed a variation of the time base method. They measured the frequency of the internal quartz oscillator by detecting the refresh rate of the stopwatch's display. [9] Another variation of the time base method was utilized by ONRJ, who measured the frequency of the stopwatch time base with a conductive membrane. Five measurements were made, each lasting for four hours.

6. Measurement Results

The environmental conditions, measurement results, and estimated uncertainty for both groups are listed in Table 5A and 5B. Although environmental conditions are recorded in the table, they were typically not included in the uncertainty analysis. The temperature coefficient of the DUT was not specified by the manufacturer, but is believed be less than 0.2×10^{-6} per ºC at normal laboratory temperatures. However, this is still large enough to account for some of the small differences in the comparison results.

Although each participant was responsible for providing their own estimation of measurement uncertainty, the submission form (Table 5) did not require participants to include the full uncertainty analysis. However, full analysis was provided by nine of the laboratories, including CENAMEP, CENAM, ICE, INDECOPI, INTI, TTBS, NRC, and NIST. This analysis is not provided here due to space limitation. Most participants used a variation of the root sum squares method,

$$U = k\sqrt{{U_A}^2 + {U_B}^2}\ , \tag{2}$$

where:

k is the coverage factor (2 in all cases);

U_A^2 is the square of the uncertainties evaluated with the Type A method; and

U_B^2 is the square of the uncertainties evaluated with the Type B method.

A few participants estimated uncertainty with other methods. For example, UTE's estimate was based on a single Type A uncertainty, the Allan deviation, $\sigma_y(\tau)$, multiplied by two to obtain a coverage factor of $k = 2$.

The laboratories that utilized the direct comparison or totalize methods each identified, as expected, that human reaction time is the largest source of uncertainty. The laboratories that utilized the time base method were primarily concerned with the uncertainty of the reference oscillator, which was obtainable through the SIMTN [3], and the uncertainty contributed by the sensors and instrumentation. There were several examples where the uncertainty estimates clearly seem to be too large or too small, but there was considerable overlap of the measurement results reported by the various laboratories, as can be seen in Figs. 3 and 4.

To conclude the analysis, CENAMEP was considered as the pivot laboratory for both groups. This was done by adjusting the measurement results of Group 2 by subtracting a constant value (2.05×10^{-6}) that represented the average difference of the frequency of the two stopwatches as measured at CENAMEP. This allowed all 13 laboratories to be included in one group. The results are shown in Fig. 5.

7. Summary and Conclusions

The first interlaboratory stopwatch comparison in the SIM region was completed in February 2011. The comparison revealed relatively good agreement among participants, even though some laboratories had no previous experience with stopwatch calibrations, and even though a wide variety of different calibration methods were employed.

The knowledge gained during the comparison could be used to develop a standard procedure for stopwatch calibrations for NMIs involved in stopwatch calibrations. Even more importantly, these procedures could be distributed to industrial laboratories that have large numbers of stopwatches to calibrate.

We also expect to hold future interlaboratory comparisons to improve the calibration and measurement capabilities of the SIM NMIs, and to further strengthen the spirit of cooperation between the laboratories. These might include additional stopwatch comparisons, or comparisons of oscillators of medium accuracy, such as the oven-controlled quartz oscillators used in test and measurement equipment.

8. References

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