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Hydraulic gauge pressure SIM comparison for a range up to 100 MPa

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Abstract. A pressure comparison was carried out within the Interamerican Metrology System (SIM). The comparison was carried out up to 100 MPa, using a high accuracy pressure balance as transfer standard (Ruska, with 0.005% accuracy class). All laboratories' standards were pressure balances. The Centro Nacional de Metrología, CENAM, Mexico, was the coordinator and pilot laboratory. The results obtained and the comparability assessment are included. An exercise, comparing two high accuracy pressure balances calibration methods is presented.

1. Introduction

At least one laboratory from each of the five different areas of SIM participated. Seven NMIs took part; Centro Nacional de Metrología (CENAM, Mexico) acted as the coordinator and pilot laboratory. The comparison started in January 2000 and finished in December 2003 using a high accuracy pressure balance as transfer standard. This comparison follows another comparison with the same range which used a high accuracy digital manometer as reference standard [1].The same measuring range as that of the CIPM Pressure Key Comparison CCM.P-K7 was used to have the possibility of linking this comparison. Taking this opportunity, NIST and CENAM made an investigation exercise of the results obtained by two calibration procedures.

2. Scope

To estimate the level of agreement among national laboratories, from 10 MPa to 100 MPa, within the SIM region. To provide a link for the CIPM Key Comparison CCM.P-K7. Table 1 presents the SIM participating laboratories.

Table 1. Participating laboratories.

SIM area	Laboratory	Person in charge	Country
Andimet	Centro de Control de Calidad y Metrología, Superintendencia Industria y Comercio (SIC)	Idrovo Calderón	Colombia
Camet	Laboratorio Costarricense de Metrología (LACOMET)	Gerardo Padilla*	Costa Rica
Carimet	Jamaica Bureau of Standards (JBS)	Allan Foreman	Jamaica
Noramet	National Institute of Standards and Technology (NIST)	Douglas Olson	USA
	Centro Nacional de Metrología (CENAM)	Pablo Olvera	Mexico
Suramet	Centro de Física, Instituto Nacional de Tecnología Industrial (CeFis-INTI)	Juan Forastieri	Argentina
	Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (INMETRO)	Paulo Couto	Brazil

* On leave from LACOMET

2.1 Transfer standard

Table 2 shows the general specifications of the transfer standard (TS) [2].

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Table 2. TS data.

Transfer Standard:	Pressure balance
Range:	up to 100 MPa
Make:	Ruska
Model:	2485
Serial number:	48875
Piston-cylinder material:	Tungsten-carbide
Piston-cylinder design:	Free deformation
Piston-cylinder serial number:	J304
Piston-cylinder model	2485-986
Accuracy class:	0.005% of the reading
Mass set serial number	48699
Mass set model	2485-940

2.2 General guidelines and procedure

The measurement protocol was elaborated by CENAM and accepted by the participants [3 - 5].

3. Participating laboratories' standards

Table 3. Participating laboratories' standards general information.

Laboratory	Piston-cylinder material	Piston-cylinder design	Range	Relative uncertainty (k = 2, %R)	Effective area $m^2 \times 10^{-6}$
CeFis-INTI	Tungsten-carbide	Free deformation	5 MPa to 100 MPa	52×10^{-4}	9.805 45
INMETRO	Tungsten-carbide	Free deformation	1 MPa to 250 MPa	56×10^{-4}	1.961 31
JBS	Stainless steel	Dual concentric piston-cylinder inner unit	Up to 110 MPa	120×10^{-4}	4.032 22
LACOMET	Tungsten-carbide	Cylinder-double piston	2 MPa to 120 MPa	230×10^{-4}	4.032 3
NIST	Tungsten-carbide	Re-entrant	7 MPa to 100 MPa	37×10^{-4}	16.802 57
SIC	Tungsten-carbide, stainless steel	Free deformation	0.2 MPa to 140 MPa	33×10^{-4} + 0.2×10^{-6}/MPa	4.035 05
CENAM	Tungsten-carbide	Free deformation	1 MPa to 100 MPa	37×10^{-4}	9.805 18

4. Results

The TS was calibrated at CENAM at the beginning and end of the comparison; see Table 4.

Table 4. *Ae*, effective areas of the TS at the beginning and at the end of the comparison and relative difference.

Pressure MPa	***Ae* 2000** m^2	***Ae* 2003** m^2	***Ae* Relative difference 2000 - 2003**
10	$9.805\ 532\times10^{-6}$	$9.805\ 500\times10^{-6}$	3.24×10^{-6}
15	$9.805\ 572\times10^{-6}$	$9.805\ 523\times10^{-6}$	4.93×10^{-6}
20	$9.805\ 607\times10^{-6}$	$9.805\ 580\times10^{-6}$	2.74×10^{-6}
30	$9.805\ 714\times10^{-6}$	$9.805\ 679\times10^{-6}$	3.51×10^{-6}
40	$9.805\ 777\times10^{-6}$	$9.805\ 756\times10^{-6}$	2.07×10^{-6}
50	$9.805\ 861\times10^{-6}$	$9.805\ 834\times10^{-6}$	2.75×10^{-6}
60	$9.805\ 940\times10^{-6}$	$9.805\ 899\times10^{-6}$	4.12×10^{-6}
70	$9.806\ 052\times10^{-6}$	$9.805\ 962\times10^{-6}$	9.11×10^{-6}
80	$9.806\ 093\times10^{-6}$	$9.806\ 032\times10^{-6}$	6.18×10^{-6}
90	$9.806\ 219\times10^{-6}$	$9.806\ 094\times10^{-6}$	1.27×10^{-5}
100	$9.806\ 288\times10^{-6}$	$9.806\ 158\times10^{-6}$	1.33×10^{-5}

Table 5 shows the differences in A_0 results for the two TS calibrations made at CENAM.

Table 5. Differences in effective area A_0, for the two calibrations.

	A_0 (m^2)	λ (Pa^{-1})
2000	$9.805\,445\times10^{-6}$	8.61×10^{-13}
2003	$9.805\,440\times10^{-6}$	7.56×10^{-13}
Relative deviation of A_0	4.9×10^{-7}	

JBS and LACOMET did not send their measurements and are not included in the results and analysis. Table 6 presents the results of A_0, effective areas and uncertainties found.

Table 6. A_0, effective areas and their associated relative standard uncertainties (u/A).

	SIC		**NIST**		**INTI**		**CENAM**		**INMETRO**	
Pressure MPa	**Area** (m^2) $\times10^{-6}$	***u*** (m^2) $\times10^{-10}$	**Area** (m^2) $\times10^{-6}$	***u*** (m^2) $\times10^{-10}$	**Area** (m^2) $\times10^{-6}$	***u*** (m^2) $\times10^{-10}$	**Area** (m^2) $\times10^{-6}$	***u*** (m^2) $\times10^{-10}$	**Area** (m^2) $\times10^{-6}$	***u*** (m^2) $\times10^{-10}$
A_0, m^2=	9.805 18	2.2	9.805 545	1.8	9.805 24	2.2	9.805 43	1.8	9.805 61	2.7
λ, MPa^{-1}	1.0	2 400	0.82	-------	-0.61	-1 800	0.77	1 000	-34	-------
10	9.805 23	1.6	9.805 65	1.8	9.805 11	1.6	9.805 50	1.6	9.805 56	2.7
15	9.805 22	2.0	9.805 68	1.8	9.805 25	1.6	9.805 52	1.6	9.805 51	2.7
20	9.805 35	2.0	9.805 73	1.8	9.805 23	1.7	9.805 58	1.6	9.805 39	2.7
30	9.805 46	1.6	9.805 78	1.8	9.804 95	1.7	9.805 68	1.7	9.805 32	2.7
40	9.805 53	2.0	9.805 86	1.8	9.805 14	1.7	9.805 76	1.7	9.805 29	2.7
50	9.805 68	1.6	9.805 94	1.8	9.804 85	2.0	9.805 83	1.7	9.805 24	2.7
60	9.805 77	2.0	9.806 03	1.8	9.804 94	2.0	9.805 90	1.7	9.805 17	2.7
70	9.805 84	1.7	9.806 11	1.8	9.804 76	2.2	9.805 96	1.7	9.805 14	2.7
80	9.805 87	2.1	9.806 18	1.8	9.804 65	2.2	9.806 03	1.8	9.805 10	2.7
90	9.805 86	2.1	9.806 27	1.8	9.804 83	2.5	9.806 09	1.8	--	--
100	9.805 97	1.9	9.806 38	1.8	9.804 66	2.5	9.806 16	1.9	--	--

The area deviation against the mean value, for each laboratory at each applied pressure, is shown in Table 7. Figure 1 presents the pressures were smallest and greatest dispersion were found.

Table 7. Relative *Ap* deviations from Ap_{mean}.

	$((Ap-Ap_{mean})/Ap_{mean})\times10^{-6}$				
Pressure MPa	**SIC**	**NIST**	**INTI**	**CENAM**	**INMETRO**
10	-18.4	24.1	-30.2	9.2	15.3
15	-22.0	24.5	-18.5	8.9	7.1
20	-10.9	27.6	-22.8	12.5	-6.4
30	2.2	35.1	-49.7	24.6	-12.1
40	1.5	35.2	-38.5	24.6	-22.8
50	17.5	43.9	-67.2	33.2	-27.5
60	21.5	47.5	-63.6	34.6	-40.0
70	28.5	55.9	-82.1	41.0	-43.3
80	30.9	62.6	-93.5	47.4	-47.4
90	9.9	52.0	-95.6	33.7	
100	18.1	60.2	-115.5	37.3	

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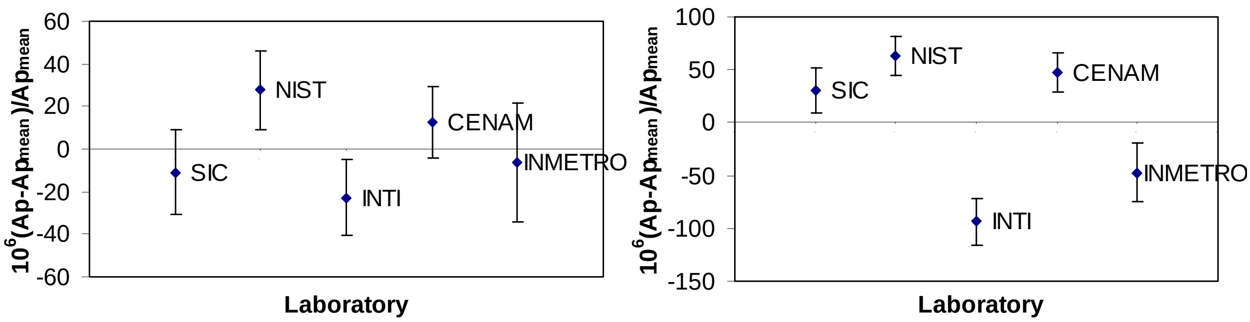

Figure 1. Relative deviations from the reference value and standard uncertainty at 20 MPa and 80 MPa.

Table 8 and Figure 2 show each laboratory's relative deviations of A_0 with respect to the A_{0mean}.

Table 8. Relative deviations of A_0 from A_{0mean}.

	$((A_0 - A_{0m}) / A_{0m})\times10^{-6}$	u_{Ao} $m^2\times10^{-10}$	u_{Ao} rel$\times10^{-6}$
NIST	17.0	1.8	18.7
INMETRO	23.1	2.7	28.0
CENAM	5.6	1.8	18.7
SIC	-22.5	2.2	22.4
INTI	-14.1	2.9	29.6

$A_{0mean} = 9.805\,38 \times 10^{-6}$ m^2

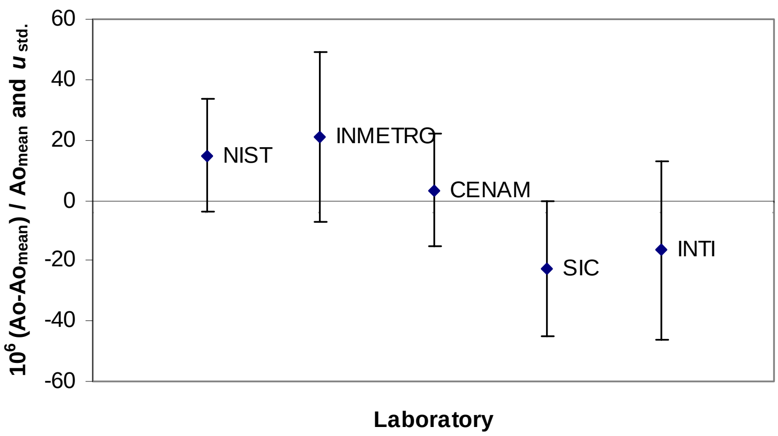

Figure 2. Relative deviations from A_{0mean} and standard uncertainty of A_0.

5. Comparison between CENAM and NIST by two different methods

An alternative method (B) was used by NIST and CENAM to verify the deviations that could be obtained with a smaller number of points measured. Method B was performed by taking 3 times each of the next measuring points: 10 MPa, 30 MPa, 50 MPa, 70 MPa and 100 MPa.

The results obtained by NIST and CENAM with method B are presented in Table 9. The original comparison method (A) results are also included.

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Table 9. *Ap* and A_0 results for each laboratory by Methods A and B.

	A Method				B Method			
	NIST		CENAM		NIST		CENAM	
Pressure (MPa)	**Area (m^2) ×10^{-6}**	***u*, (m^2) ×10^{-10}**	**Area (m^2) ×10^{-6}**	***u*, (m^2) ×10^{-10}**	**Area (m^2) ×10^{-6}**	***u*, (m^2) ×10^{-10}**	**Area (m^2)×10^{-6}**	***u*, (m^2) ×10^{-10}**
A_0	9.805 54	1.8	9.805 43	1.8	9.805 51	1.8	9.805 45	1.8
10	9.805 65	1.8	9.805 50	1.6	9.805 61	1.8	9.805 47	1.6
15	9.805 68	1.8	9.805 52	1.6				
20	9.805 73	1.8	9.805 58	1.6				
30	9.805 78	1.8	9.805 68	1.7	9.805 78	1.8	9.805 70	1.6
40	9.805 86	1.8	9.805 76	1.7				
50	9.805 94	1.8	9.805 83	1.7	9.805 92	1.8	9.805 85	1.7
60	9.806 03	1.8	9.805 90	1.7				
70	9.806 11	1.8	9.805 96	1.7	9.806 09	1.8	9.805 98	1.7
80	9.806 18	1.8	9.806 03	1.8				
90	9.806 27	1.8	9.806 09	1.8				
100	9.806 38	1.8	9.806 16	1.9	9.806 38	1.8	9.806 16	1.9

Figure 3 shows effective areas found by NIST and CENAM in each pressure by each method.

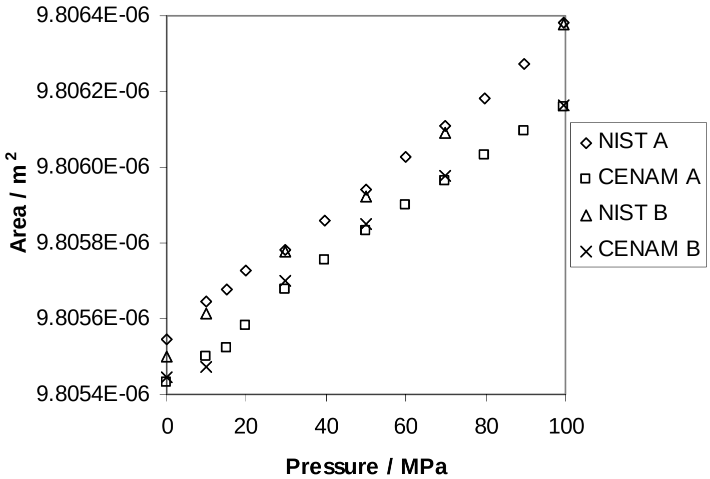

Figure 3. Effective areas for each laboratory obtained by each of the two methods.

Table 10 includes the relative deviations and the standard normalized error equation between the two methods.

Table 10. Relative deviations between methods A and B, for each pressure.

Pressure	**Deviation ((*Ap* B - *Ap* A)/*Ap* A)×10^{-6}**		**Standard normalized error**	
MPa	**CENAM**	**NIST**	**CENAM**	**NIST**
0	1.2	-3.4	0.05	0.13
10	-2.6	-3.3	0.11	0.13
30	2.2	-0.5	0.09	0.02
50	1.7	-1.7	0.07	0.06
70	1.5	-1.8	0.06	0.07
100	0.4	-0.3	0.02	0.01

6. Conclusions

To compare the results of A_0 obtained by the laboratories, the normalized error equation has being used, see Table 11.

Table 11. A_0 **s**tandard normalized error equation values among the participating laboratories.

Laboratory	NIST	INMETRO	CENAM	SIC	INTI
NIST	--	0.18	0.43	1.27	0.89
INMETRO	0.18	--	0.52	1.21	0.91
CENAM	0.43	0.52	--	0.88	0.56
SIC	1.27	1.21	0.88	--	0.16
INTI	0.89	0.91	0.56	0.16	--

The only values above 1.00 are between SIC and NIST and between SIC and INMETRO. Nevertheless, these values are below 1.30 and it is important to notice that standard uncertainties have been used, making this analysis very strict. It can be concluded that there are agreement among the laboratories in the range compared.

From the comparison results obtained by methods A and B, used by NIST and CENAM, the relative deviations between the methods are negligible (for both NIST and CENAM below 3.5×10^{-6}). The standard normalized error equation values in all cases were below 0.15. Since this first exercise shows no difference between the two methods, its application to high accuracy pressure balances calibration is worth investigating, as it requires greatly reduce effort.

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