FINAL REPORT OF SUPPLEMENTARY COMPARISON SIM.M.P-S7
Hydraulic Pressure Comparison from 7 MPa to 70 MPa

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ABSTRACT

This report presents the final results of supplementary comparison SIM.M.P-S7 in the field of hydraulic pressure up to 70 MPa, within the PTB-ANDIMET-PLUS project. Seven national pressure reference laboratories participated in this comparison, which started with an opening meeting in November 2011 at the city of Lima, the closing meeting having been held at the National Metrology Institute of Colombia INM, at Bogota, on November 27th and 28th, 2012. Each participating laboratory used for the comparison its best hydraulic pressure balance standard in the range from 7 MPa to 70 MPa. The transfer standard for the comparison was a digital manometer DH Instruments Fluke RPM-4 with an accuracy of 0.008 % of the reading.
The reference laboratory and advisor for the comparison was CENAM, Mexico. The comparison protocol and results analysis was made by the pressure laboratory of National Metrology Institute INM (Colombia) who participated in the comparison as well.

***Keywords**: Comparison, National reference laboratories, Pressure balance.*

Content

1. INTRODUCTION

This comparison is identified in the Inter-American Metrology System as SIM.M.P-S7 and is part of the Andean Region development program coordinated quality infrastructure. It was planned to confirm and strengthen the Calibration and Measurement Capabilities (CMCs) declared in hydraulic pressure in the measuring range 7 MPa to 70 MPa. It also allows setting the level of concordance of the national metrology institutes of the Andean Community of Nations and of the national laboratories of Uruguay and Paraguay in the field of pressure with respect to the reference pressure provided by CENAM, Mexico. The comparison of national laboratories was funded by the Physikalisch Technische Bundesanstalt, PTB in Germany.

2. OBJECTIVES

The objectives were to establish the differences in the calibration of transducers relative pressure in the range of 7 MPa to 70 MPa, with 0.008 % accurate reading, and to determine the uncertainties deviations of each participating laboratory [1], with respect to the reference value issued by CENAM.

3. PARTICIPATING LABORATORIES

All participating laboratories used as measurement standard their best balance of hydraulic pressure assembly with a piston-cylinder in the range from 7 Mpa to 70 MPa.
The participating laboratories were:
-National Metrology Centre, CENAM of Mexico, which acts as advisor of the supplementary comparison and sets the reference values.
-National Institute Antitrust Intellectual Property, INDECOPI of Peru.
-Bolivian Institute of Metrology, IBMETRO of Bolivia.
-Ecuadorian Standardization Institute, INEN of Ecuador.
-National Metrology Institute of Colombia, Colombia INM.
-Technological Laboratory of Uruguay, LATU of Uruguay.
-National Institute of Technology, Standardization and Metrology, INTN of Paraguay.

4. TRANSFER STANDARD CHARACTERISTICS

Brand	FLUKE DH Instruments
Model	RPM4
Serial No	119
Accuracy	0.008 % of reading
Unit	MPa
Resolution	0.000 1 MPa

A digital manometer was used as the transfer standard of pressure. Its technical characteristics are as follows:

Table1. Transfer standard characteristics

5. COMPARISON PROGRAM

The programming of the comparison round was decided in Lima, Peru, in November 2011 at a meeting of the participating laboratories.

At those same meeting general guidelines where presented; the idea was that each laboratory measures as it usually does.

Table 2 presents the planned and the executed round, with the technical characteristics of the equipment used by each laboratory.

Table 2. Specifications of participating laboratories.

Country	**Colombia**	**Ecuador**	**Bolivia**	**Perú**	**Paraguay**	**Uruguay**
Institute	INM.	INEN.	IBMETRO.	INDECOPI.	INTN.	LATU.
Calibrated by	Juan Carlos Gil R. jgil@inm.gov.co	Alexandra Benavides. abenavides@inen.gob.ec	Abelardo Reyeros Rivera areyeros@ibmetro.gob.bo	Leonardo de la Cruz, ldelacruz@indecopi.gob.pe	Natalia Vega Gamarra nvega@intn.gov.py	Pablo Constantino; Alejandro Acquarone pconstan@latu.org.uy
Planned measurement dates	2 to 16 of January/2012	January 18 to February 1/2012	March 26 to April 9/2012	11 to 25 April / 2012	3 to 17 Feb / 2012	February 21 to March 6/2012
Installation Date	2011-12-19	2012-01-19	2012-03-23	2012-05-05	2012-02-08	17/02/2012
Date of calibration	2011-12-22	2012-01-24	2012-03-30	2012-05-09	2012-02-14	22/02/2012
Best measurement capability accredited	$4.0 \times 10^{-5} \times p_e$ + 57 Pa	0.05% Non-accredited	******	5e-5	0.02 % L	CMC presentation process
Fluid	Shell Tellus oil 22	Oil	Sebacate	oil	D22 Oil	Sebacate
Equipment used as a standard	Hydraulic Pressure Balance p/c 70 MPa	Hydraulic Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance
Brand	Pressurements	GE Sensing Pressurements	DREYER	RUSKA	WIKA	DHI
Model	7800/5M	P3125-4	NO INDICATED	2400-700-00	CPB5000	PG 7302 / PC 7300-2
Series No	9952	67680	1224	20439	50362	1676
Identification	Pressure Balance - Piston K600 - 70 MPa	14101040384-0-39	******	LFP 01 007	LPR – PR – 02	N° LATU 24046
Accuracy	0.005 % of reading	0.008%	200 ppm	0.005% RD	0.01%	******
Unit	MPa	kPa	******	Pa	100 MPa	******
Resolution	61 Pa	Mass base 2000 kPa	******	29 Pa	******	******
Scope	7 MPa	7000 kPa	******	******	7 MPa	70 MPa con 35 kg
***U, k* = 2**	57 Pa + 3e-5 p_e + 1,8e-13 p_e^2/Pa	± 0.008%	200 ppm	U = 0.35 mbar + 3.9e-5p + 2.9e-8 p^2/bar	0.01 % L	******
Traceability	PTB 30254/11	Pressurements – USA	0043 PTB 05	PTB	PTB	CENAM – LATU (masa)

The transfer standard of the comparison was measured firstly by CENAM, and after the others laboratories measured again to detect possible drift of the transfer standard between the start and end of the comparison.

No influence due to drift of the transfer standard was detected. The manometer used for the comparison had no significant drift, less than 2×10^{-6} relative to the reading.

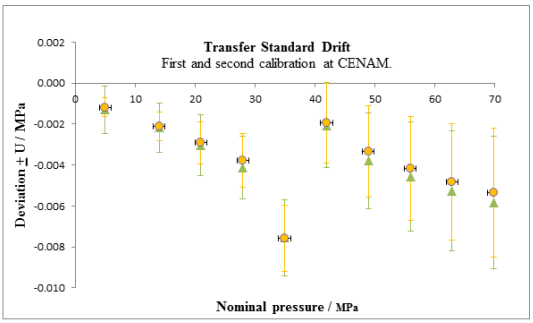

Fig1 Transfer Standard Drift

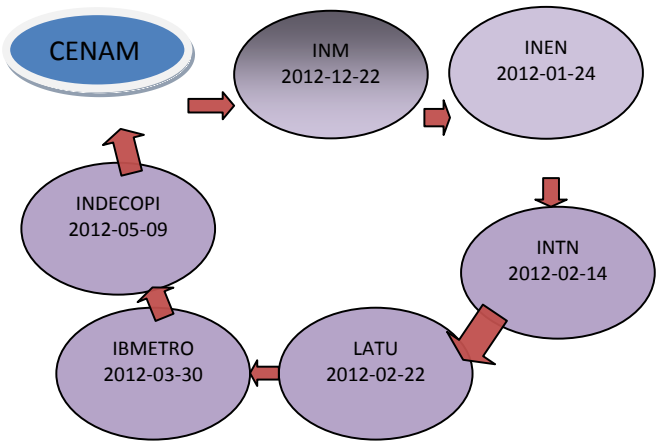

Figure2. Round comparison measurements.

The dates under the acronyms of the laboratories correspond to the dates of calibration.

It was suggested during the meeting in Lima to cover the range starting from 10 %, so that the nominal values of the first measurement point should be very close to 7 MPa, according to the values the balance of pressure of each institution was able to reproduce.

Other points of hydraulic nominal pressure were: 14 MPa, 21 MPa, 28 MPa, 35 MPa, 42 MPa, 49 MPa, 56 MPa, 63 MPa and 70 MPa.

6. MATHEMATICAL MODEL FOR PRESSURE

In this calibration pressure balances were used as the standards for laboratories. Values were established from measurements of the transfer standard by direct comparison of indications of pressure with pressure values generated by the pressure standard.

From equation 1 we can obtain the pressure generated by standard [2].

$$P_{gen} = \frac{M\, g_l\left(1-\frac{\rho_a}{\rho_M}\right)+\sigma Cir}{A_0(1+\lambda P_N)(1+\alpha(t-t_0))} + (\rho_f - \rho_a) g_l \Delta h$$

(1)

The mathematical model used for this calibration is as follows [2]:

$$\Delta p = P_{ind} - P_{std} + \sum_{i=1}^{N} \delta P_i \qquad \textbf{(2)}$$

Each laboratory made corrections to their particular calibration.

7. RESULTS

Figures from 2 to 12 show deviations and uncertainties reported by the participants [3] for the different nominal values of the measured pressure. Figure 13 shows the error curves of the participants with their associated uncertainties.

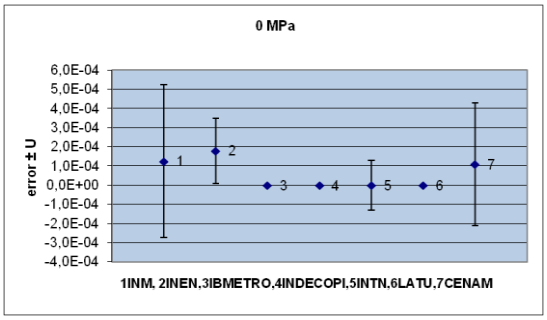

Figure3. Results at 0 MPa

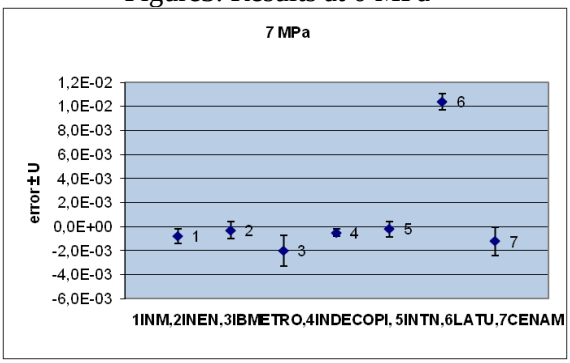

Figure4. Results at 7 MPa

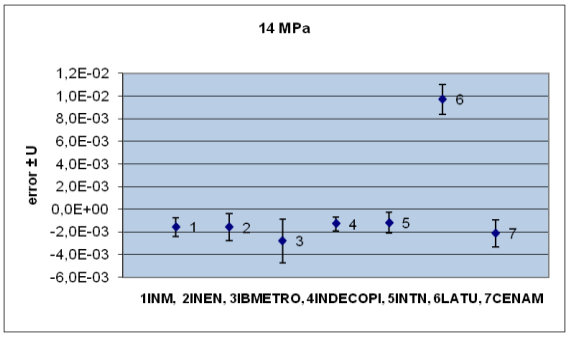

Figure5. Results at 14 MPa

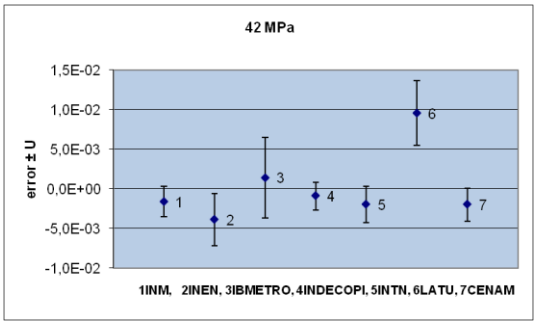

Figure9. Results at 42 MPa

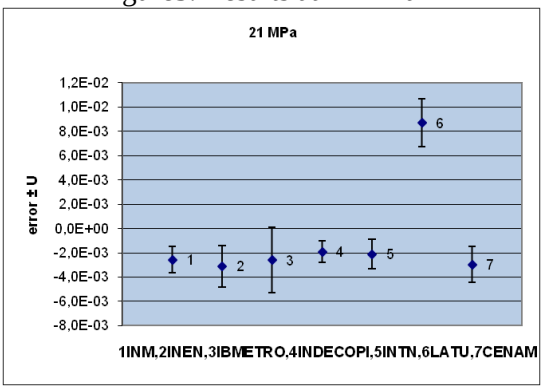

Figure6. Results at 21 MPa.

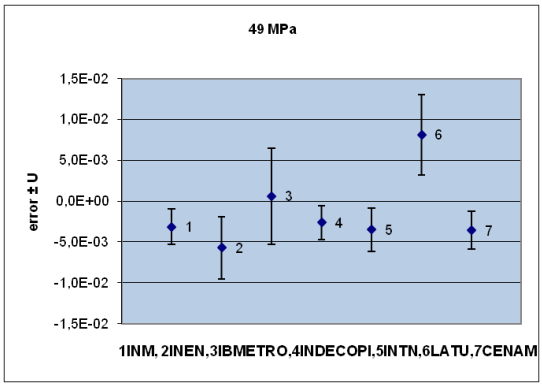

Figure10. Results at 49 MPa

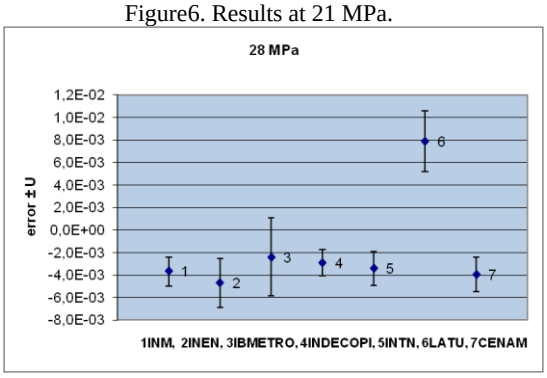

Figure 7. Results at 28 MPa

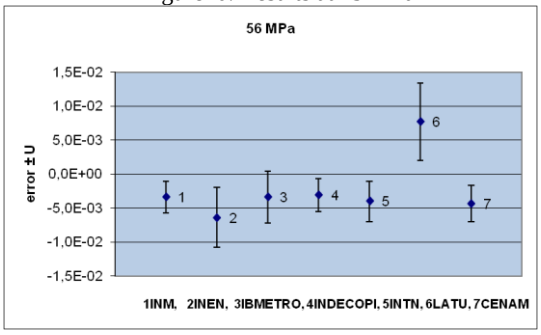

Figure11. Results at 56 MPa

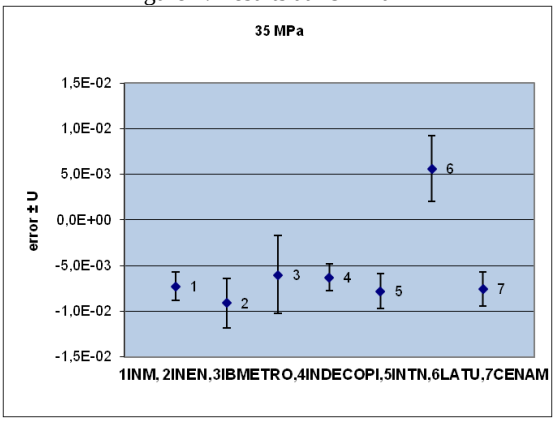

Figure8. Results at 35 MPa

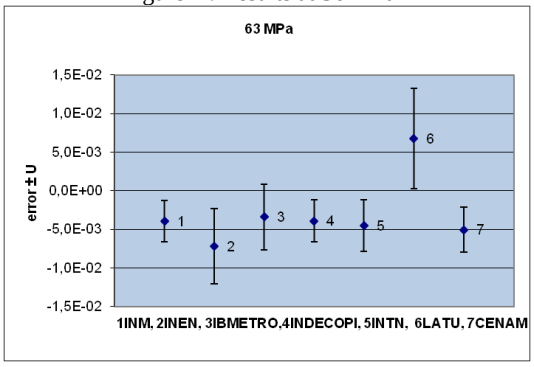

Figure12. Results at 63 MPa

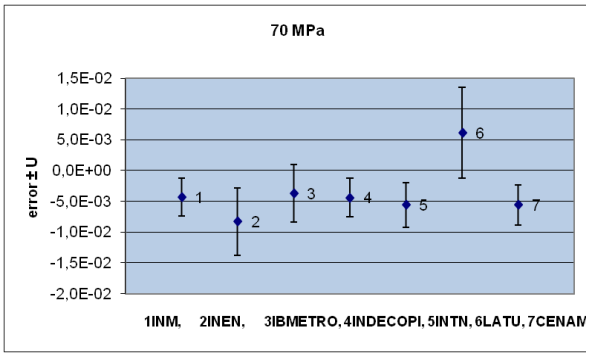

Figure13. Results at 70 MPa

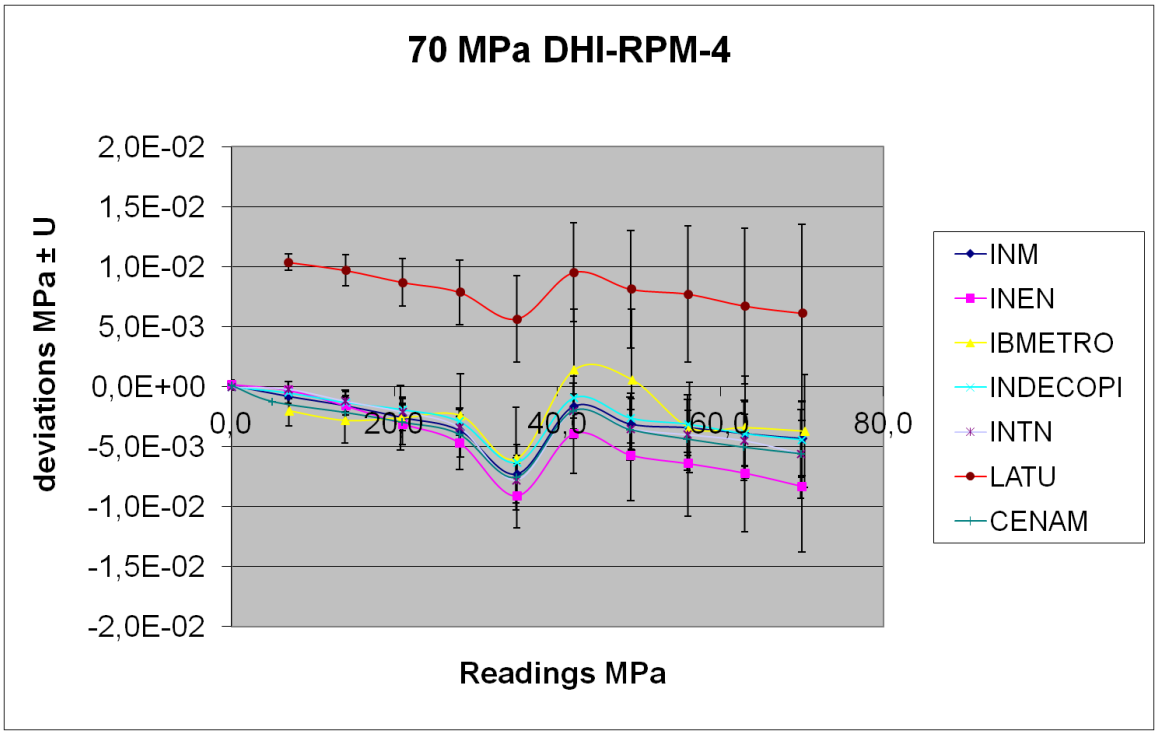

Figure14. Uncertainty with error curves of all participating laboratories (7 MPa to 70 MPa).

Table 3 presents the estimated uncertainty contributions of the participating laboratories.

Table3.Contributions to the standard measurement uncertainty, *u*

	Uncertainty sources	INM	INEN	IBMETRO	INDECOPI	INTN	LATU
***u* max, MPa**	**Type A**	3.33 E-04	3.175 E-04	2.9 E-05	1.11 E-04	3.175 E-04	2.6 E-04
	Standard	1.51 E-03	2.74 E-03	4.699 E-03	1.563 E-03	3.220 E-04	3.5 E-03
	Resolution	2.89 E-05	1.732 E-04	5.8 E-05	2.9 E-05	2.887 E-05	2.9 E-05
	Zero drift	1.44 E-04	1.4 E-04	2.9 E-05	0.000 E+00	0.000 E+00	2.0 E-04
	Hysteresis	1.73 E-04	1.73E-04	2.6 E-05	1.155 E-04	1.588 E-04	7.0 E-04
	Oil column	9.70 E-06	8.58E-04	4.44 E-04	3.6 E-06	2.452 E-07	2.3 E-06

7.1. Performance of participants using the normalized error, E_n

To analyze the compatibility of the results

obtained by each laboratory with respect to the established reference values, we used the normalized error criteria. The equation used is [4]:

$$E_n = \frac{\bar{e} - \bar{E}}{\sqrt{U_{lab}^2 + U_{ref}^2}} \qquad (3)$$

Where:

$\bar{e}$: is the average error of a participating laboratory

$\bar{E}$: is the average error as determined by the reference

U_{lab}: is the expanded uncertainty of a participating laboratory

U_{ref}: is the expanded uncertainty of the reference

The normalized error can fluctuate between a positive OR negative value. If a participant gets normalized error values between -1 and +1, with an acceptable estimate of their uncertainties, it can be concluded that the laboratory has a satisfactory, reliable and competent performance. The normalized error criterion is: $|E_n| \leq 1.0$ for satisfactory performance and $|E_n| > 1.0$ for unsatisfactory performance.

The following figures provide the performance of each laboratory evaluated using the normalized error.

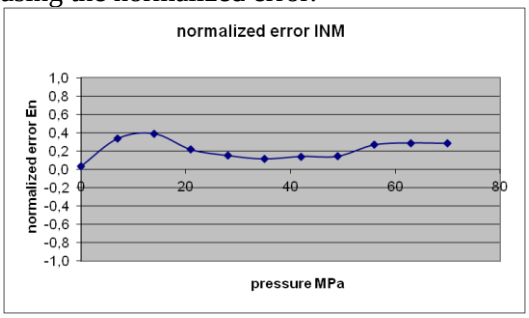

Figure 15. E_n INM.

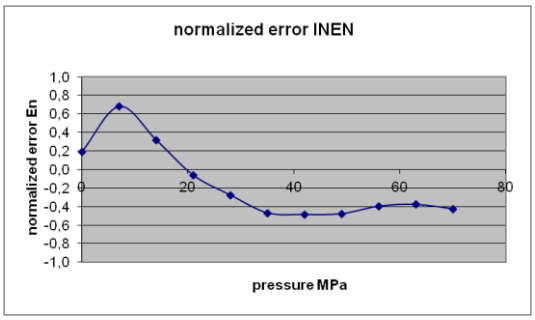

Figure 16. E_n INEN.

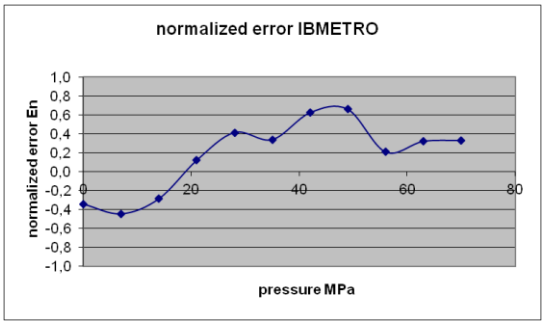

Figure 17. E_n IBMETRO.

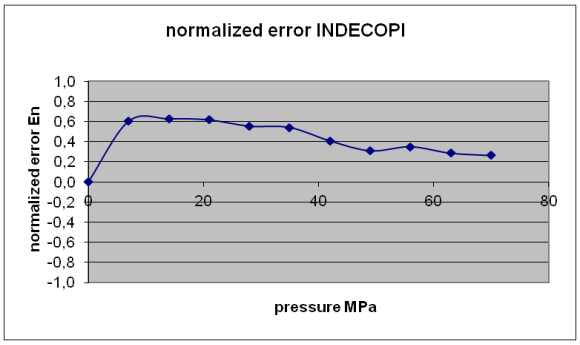

Figure 18. E_n INDECOPI.

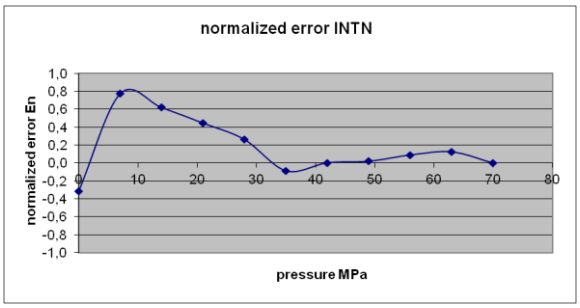

Figure 19. E_n INTN.

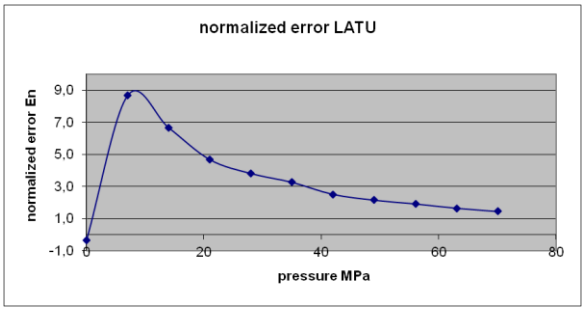

Figure20. E_n LATU.

8. DISCUSSIONS

It can be seen that when more data measured is consistent with the reference values, the normalized error trend curve exhibits less fluctuations.

Fluctuations most occur in the first 20 % part of the measuring range. This is perhaps due to preheating preloads or piston-cylinder assemblies used below its 10 % confidence indicated interval.

Attention should be given to the value of zero, how to measure it, to correct it and how to estimate its uncertainty.

To complete this report it would be useful to have information concerning the participating laboratories:
a) Guide calibration or calibration method applied.
b) Interval indication of the scale used.
c) Drawbacks in moving the instrument that was used.
d) Whether the receipt and delivery formats where properly filled.
e) Whether the delivery forms where handed in.
e) The reference laboratory balance used for this comparison.

9. CONCLUSIONS

All laboratories have a satisfactory level of normalized error except LATU of Uruguay.

LATU should review their corrections to the pressure generated and / or the height of fluid (hydrostatic pressure), which may have influence on the deviation. As shown in Figure 13, there is a constant running error, even though the error curve fits and behaves similar to other participating laboratories.

All uncertainties overlap the reference value, except for LATU (curve running of errors).

There was no significant inconvenience in delaying the comparison and one concluded that it was best to move the measurement equipment as hand luggage, carrying the letters corresponding to entrance permits for each country, and that the value of the instrument did not exceed $ 1000 USD.

10. ACKNOWLEDGEMENTS

Special thanks to Dr. Jorge C. Torres, Director of the Force and Pressure Metrology National Center CENAM Mexico for their invaluable collaboration.

Thanks to my lab partner, María Catalina Neira R Engineer, for those long days of measurement and their valuable contribution.

Acknowledgements and thanks to the professional, dedicated and enthusiastic Metrologists of the participating labs.

We thank particularly the support and collaboration of Physikalisch Technische Bundesanstalt, PTB in Germany, for their coordination, logistics and funding for this comparison.

11. REFERENCES

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[2] Deutscher Kalibrieerdienst DKD. *Guideline DKD-R 6-1 Calibration of Pressure Gauges. March 2003.*

[3] Norma ISO 17025 *Requisitos Generales para la competencia de laboratorios de calibración y ensayo. 2003.*
[4] ISO 13528. *Métodos estadísticos para su uso en ensayos de aptitud por comparaciones interlaboratorios. 2005.*

INM			**Colombia**		**INEN**			**Ecuador**	
Standard Pressure **PL MPa**	**Average readings PT MPa**	**Error PT-PL MPa**	***u* Combined standard MPa**	***U* Expanded *k*=2 MPa**	Standard Pressure **PL MPa**	**Average readings PT MPa**	**Error PT-PL MPa**	***u* Combined standard MPa**	***U* Expanded *k*=2 MPa**
0.00000	0.0001	1.25E-04	2.00E-04	4.00E-04	0.00000	0.00018	1.80E-04	8.66E-05	1.70E-04
6.98599	6.9852	-7.90E-04	2.96E-04	5.91E-04	6.9999	6.9996	-3.00E-04	3.50E-04	7.00E-04
14.01748	14.0159	-1.58E-03	4.10E-04	8.19E-04	14.0006	13.9990	-1.60E-03	5.96E-04	1.20E-03
20.99885	20.9963	-2.57E-03	5.33E-04	1.07E-03	21.0008	20.9978	-3.10E-03	8.41E-04	1.70E-03
28.02964	28.0260	-3.66E-03	6.44E-04	1.29E-03	28.0008	27.9961	-4.70E-03	1.10E-03	2.20E-03
35.01017	35.0029	-7.30E-03	7.80E-04	1.56E-03	35.0007	34.9917	-9.10E-03	1.36E-03	2.70E-03
41.99014	41.9885	-1.62E-03	9.50E-04	1.90E-03	42.0005	41.9966	-3.90E-03	1.63E-03	3.30E-03
49.01972	49.0166	-3.12E-03	1.06E-03	2.13E-03	48.9995	48.9938	-5.70E-03	1.91E-03	3.80E-03
55.99904	55.9956	-3.41E-03	1.17E-03	2.34E-03	55.9983	55.9919	-6.40E-03	2.19E-03	4.40E-03
62.97799	62.9741	-3.91E-03	1.33E-03	2.67E-03	62.9966	62.9894	-7.20E-03	2.47E-03	4.90E-03
70.00637	70.0021	-4.32E-03	1.55E-03	3.10E-03	69.9949	69.9866	-8.30E-03	2.77E-03	5.50E-03
IBMETRO			**Bolivia**		**INDECOPI**			**Perú**	
0.0000					0.0000	0.0000	0.00E+00	----	----
7.0817	7.08385	-2.00E-03	6.50E-04	1.29E-03	6.9979	6.9974	-5.00E-04	1.60E-04	3.20E-04
13.9207	13.92363	-2.80E-03	9.70E-04	1.93E-03	13.9983	13.9970	-1.30E-03	2.90E-04	5.90E-04
20.7606	20.76335	-2.60E-03	1.34E-03	2.68E-03	21.0059	21.0040	-1.90E-03	4.30E-04	8.70E-04
28.0899	28.09247	-2.40E-03	1.73E-03	3.46E-03	27.9985	27.9956	-2.90E-03	5.80E-04	1.15E-03
34.9270	34.93323	-6.00E-03	2.13E-03	4.26E-03	35.0011	34.9948	-6.30E-03	7.20E-04	1.44E-03
42.0205	42.01934	1.40E-03	2.54E-03	5.08E-03	41.9851	41.9842	-9.00E-04	8.80E-04	1.75E-03
49.1059	49.10565	6.00E-04	2.95E-03	5.89E-03	48.9843	48.9817	-2.60E-03	1.03E-03	2.07E-03
56.1758	56.17913	-3.40E-03	1.89E-03	3.78E-03	55.9800	55.9769	-3.10E-03	1.20E-03	2.40E-03
63.0177	63.02111	-3.40E-03	2.12E-03	4.25E-03	62.9785	62.9746	-3.90E-03	1.38E-03	2.76E-03
70.3477	70.35131	-3.70E-03	2.36E-03	4.72E-03	69.9753	69.9709	-4.40E-03	1.56E-03	3.13E-03
INTN			**Paraguay**		**LATU**			**Uruguay**	
Standard Pressure **PL MPa**	**Average readings PT MPa**	**Error PT-PL MPa**	***u* Combined standard MPa**	***U* Expanded *k*=2 MPa**	Standard Pressure **PL MPa**	**Average readings PT MPa**	**Error PT-PL MPa**	***u* Combined standard MPa**	***U* Expanded *k*=2 MPa**
0.0000	0.0000	0.00E+00	7.00E-05	1.30E-04					
6.9885	6.9883	-2.00E-04	3.20E-04	6.40E-04	7.00000	7.01038	1.04E-02	3.30E-04	6.70E-04
13.9768	13.9757	-1.20E-03	4.60E-04	9.30E-04	14.00000	14.0097	9.70E-03	6.60E-04	1.30E-03
20.9651	20.9630	-2.10E-03	6.20E-04	1.24E-03	21.00000	21.0087	8.70E-03	1.00E-03	2.00E-03
27.9532	27.9498	-3.40E-03	7.50E-04	1.51E-03	28.00000	28.0079	7.87E-03	1.40E-03	2.70E-03
34.9411	34.9334	-7.80E-03	9.40E-04	1.87E-03	35.00000	35.0056	5.64E-03	1.80E-03	3.60E-03
41.9291	41.9271	-2.00E-03	1.15E-03	2.29E-03	42.00000	42.0095	9.54E-03	2.10E-03	4.10E-03
48.9171	48.9136	-3.50E-03	1.31E-03	2.62E-03	49.00000	49.0081	8.13E-03	2.40E-03	4.90E-03
55.9050	55.9009	-4.00E-03	1.48E-03	2.96E-03	56.00000	56.0077	7.72E-03	2.80E-03	5.70E-03
62.8929	62.8883	-4.50E-03	1.67E-03	3.34E-03	63.00000	63.0067	6.72E-03	3.20E-03	6.50E-03
69.8806	69.8751	-5.60E-03	1.84E-03	3.68E-03	70.00000	70.0061	6.12E-03	3.70E-03	7.40E-03

12 ANNEXES

Table 4 Measurement results of participants

Table 5 Results of measurement reference

CENAM		MÉXICO	
Standard Pressure PL MPa	**Average Readings PT MPa**	**Error PT-PL MPa**	***Uncertainty* Expanded U; *k*=2 MPa**
0.000000	0.00011	1.10E-04	3.20E-04
4.986875	4.98565	-1.23E-03	1.16E-03
13.962945	13.9608	-2.15E-03	1.21E-03
20.94426	20.9413	-2.96E-03	1.49E-03
27.92546	27.9215	-3.96E-03	1.53E-03
34.906565	34.899	-7.57E-03	1.84E-03
41.887555	41.88555	-2.01E-03	2.07E-03
48.868465	48.8649	-3.57E-03	2.34E-03
55.849305	55.84495	-4.36E-03	2.68E-03
62.829995	62.82495	-5.05E-03	2.93E-03
69.81063	69.80505	-5.58E-03	3.24E-03