TECHNICAL PROTOCOL

FORCE KEY COMPARISON

SIM.M.F-K3.a (1 000 kN)

Pilot Laboratory
Instituto Nacional de Metrología de Colombia, (INM)

Instituto Nacional de Tecnología Industrial, (INTI)

Force Laboratory

(Version 4)
September 2024

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1. Introduction

In a virtual meeting held on 17th March 2023, the SIM working group decided to make a comparison in 1 MN, taking into account that it is essential to demonstrate technical competence and equipment. Additionally, at the meeting, it was determined that there would be two pilot laboratories, INTI (Instituto Nacional de Technology Industrial) of Argentina and INM (Instituto Nacional de Metrología) of Colombia, to be able to share the tasks involved in this activity.
NIST (National Institute of Standards and Technology) will be the reference laboratory, and the measurement device will be awarded by the INM of Colombia. INM of Colombia and INTI of Argentina will be responsible for monitoring standard performance during circulation, evaluation, and reporting of the comparison results.

2. Measurement device

For this comparison, one reference force transducer was selected with the following characteristics:

Table 1. Details of the measurement device

Manufacturer	Model	Serial	Capacity	Picture
HBM	C18	00283N54	1000 kN	

Fitting pads (load button and thrust piece) and the connection cable are provided by the force laboratory from INM from Colombia. Each participating laboratory should check that all load transfer surfaces of the transducer and the reference machine used are clean and in good condition before mounting and measurement. The transducer should be carefully mounted, paying particular attention to its alignment on the device before starting measurements.

This standard was chosen for its high accuracy and stability over time.

In addition, the HBM BN100A model device with the force transducer will be sent for the control of the DMP 40 or DMP 41 device.

The traveling standards and HBM BN100A will be supplied by INM of Colombia, details can be found in the Table 2.

Table 2. Details of the bridge calibration unit

Manufacturer	Model	Serial	Picture
HBM	BN100 A	11128	

2.1. Electrical traceability

Force sensor measurements will be made using a digital amplifier such as HBM's DMP 40 or DMP 41. To ensure consistency between the reference lab measurement and each participant's measurement, a BN100A reference bridge calibration unit with transducers will be circulated to correct the difference between the participant's and the pilot's bridge amplifier.

3. Organization

The organization will be coordinated by the pilot's laboratories, particularly by Eng. Alejandro Savarin from INTI (asavarin@inti.gob.ar) and Eng. Ivan Betancur from INM (ibetancur@inm.gov.co).

The technical protocol has been drafted by the pilot laboratory with assistance from INTI, based on similar documents. The technical protocol was sent to all participants before circulating the artifacts.

3.1. Requirements for participation

Participating laboratories must have the appropriate equipment to provide force transducer calibration services and should offer this calibration service regularly to their clients.

A schedule will be made further in the organization of the comparison. Each laboratory involved in planning is allocated two weeks for measurement and two weeks for transporting the transfer standard.

3.2. Participants

The reference laboratory for this comparison is the force laboratory from NIST (USA) and the pilot force laboratories for this comparison are INTI (Argentina) and the Instituto Nacional de Metrologia de Colombia (INM). The contact details of the coordinator and participant institutions are as follows:

Table 3. Participants information

Laboratory	Address	Contact Person
National Institute of Standards and Technology - NIST (reference)	100 Bureau Drive Gaithersburg, MD 20899	Kevin Chesnutwood (kevin.chesnutwood@nist.gov)
Instituto Nacional de Tecnología Industrial - INTI (pilot)	Av. General Paz Nº 5445, San Martín, Buenos Aires.	Alejandro Savarin (asavarin@inti.gob.ar)
Instituto Nacional de Metrología de Colombia - INM (pilot)	AV carrera 50 # 26-55 INT 2 CAN	Juan Alberto Arias Prieto (jarias@inm.gov.co) Iván Betancur Pulido (ibetancur@inm.gov.co)
Instituto de Investigaciones y Control - IDIC	Av. Libertador Bernardo O'Higgins 1449 Torre N° 7, Santiago Downtown, Piso 16	Christian Villarroel Poblete (cvillarroel1@gmail.com)
Centro Nacional de Metrología - CENAM	km 4.5 Carretera a Los Cués Municipio El Marqués 76246 Querétaro	Jorge Torres-Guzmán (jtorres@cenam.mx) Alejandro Cárdenas (acardena@cenam.mx)
Instituto Ecuatoriano de Normalización - INEN	Baquerizo Moreno E8-29 y Diego de Almagro Quito	Wilson Angulo (wangulo@normalizacion.gob.ec (svicente@normalizacion.gob.ec)
Instituto Nacional de Metrologia, Qualidade e Tecnologia - INMETRO	Av. Nossa Senhora das Graças, 50 - Xerém, Duque de Caxias - RJ - 25250-020	Rafael Soares de Oliveira (rsoliveira@inmetro.gov.br)
Laboratorio Nacional de Materiales y Modelos Estructurales - LanammeUCR	Universidad de Costa Rica, Ciudad de la Investigación, Finca 2, San José, San Pedro, Costa Rica	Humberto Tioli (jose.tioli@ucr.ac.cr)

3.3. Time schedule

The comparison is organized in a two-loop. Each laboratory will have one month to make its measurements and to prepare for transportation to the next participant. The schedule was designed to fit within the preferences of the laboratories for scheduling the measurements and any changes to the schedule, after the start of the circulation, will be discussed and agreed upon among the participants and the TC-F (Technical Committee - Force) chairman. The reference laboratory, NIST will make three measurements to check the stability of the Travelling Standard, the reference value will be the corrected to the KCRV through the comparison CCM.F-K3.a, in addition, for each laboratory, the reference value will be calculated by temporal linear interpolation between the immediately preceding and immediately succeeding measurements conducted by the reference laboratory.

Once a participant has completed their measurements and is ready to ship the traveling standards the next scheduled participant along with the pilot institute should be notified. All items should be inspected and packed into the original carrying case and sent to the next participant promptly so as to avoid delay.

There will be sent the participant with appropriate documents for customs formalities. The participant will be informed before the devices are shipped.

The measurement scheme can be seen in Table 4. It is also important to note that participating NMIs must strictly respect the time allotted for their participation.

Table 4. Planning of the measurements and declared uncertainties.

<table>
<tr><th>NMI</th><th>Country</th><th>Date</th><th colspan="2">Uncertainty</th></tr>
<tr><td>NIST (reference)</td><td>United States of America</td><td>August 2023</td><td colspan="2">1.0E-5</td></tr>
<tr><td>CENAM</td><td>Mexico</td><td>December 2023</td><td colspan="2">9.5E-4</td></tr>
<tr><td rowspan="2">IDIC</td><td rowspan="2">Chile</td><td rowspan="2">January 2024</td><td>500 kN</td><td>5E-4</td></tr>
<tr><td>1 MN</td><td>1E-3</td></tr>
<tr><td>INM (pilot 1)</td><td>Colombia</td><td>May 2024</td><td colspan="2">2.0E-4</td></tr>
<tr><td>NIST (reference)</td><td>United States of America</td><td>October 2024</td><td colspan="2">1.0E-5</td></tr>
<tr><td>INTI (pilot 2)</td><td>Argentina</td><td>November 2024</td><td colspan="2">2.0E-4</td></tr>
<tr><td>Lanamme UCR</td><td>Costa Rica</td><td>December 2024</td><td colspan="2">1.0E-3</td></tr>
</table>

NMI	Country	Date	Uncertainty
INEN	Ecuador	January 2025	1.0E-3
INMETRO	Brazil	February 2025	1.0E-4
NIST (reference)	United States of America	March 2025	1.0E-5
INM (pilot 1)	Colombia	April 2025	2.0E-4

3.4. Transportation

Each participant must assume the costs of transporting and insurance the traveling standards to the next participant or shipping to NIST, as appropriate. Also, they should be guaranteed that the shipment has an insurance policy.

In addition, the traveling standard must be delivered to the airport of the consignee participant, who will be responsible for the customs and clearance formalities into the country of the receiving institute.

To ensure that the traveling standard keeps appropriate - optimum conditions for comparison, before starting new measures the consignee should fill out the form in Annex 1 completely and send it to the pilot laboratory immediately, together with photographs showing the condition of each of the items received.

Upon completion of measurements, the participant shall inform the next participant and the pilot laboratory by e-mail about the shipment of the traveling standards using the form Annex 2.

Participating laboratories will receive 1 (one) force transducer and 1 (one) BN100A device in separate boxes.

The travel standard is packed in a (46 x 36x 28) cm transport case with a total weight of 23 kg and the BN100 A bridge calibration unit is in a (56 x 45 x 26) cm transport case with a weight of 15 kg.

Both cases can be easily opened for customs inspection, additionally, all necessary documentation for customs clearance will be sent in advance.

3.5. Failure of Travelling Standard

On receipt of the traveling standards the participant must inspect each standard for damage. If any damage is observed this must be reported to the pilot institute prior to the continuation of the measurement See section 2.3 for details. **Please do not touch with bare hands, use gloves.**

In case of any damage or malfunction of the traveling standard, the comparison will continue after the traveling standard has been repaired and verified.

3.6. Financial aspects

Each participant laboratory is responsible for its own costs for the measurements as well as any damage that may occur within its country. The pilot laboratory has no insurance for any loss or damage to the traveling standard.

4. Transfer Standard

The transfer standard or traveling standard is given in Table 1. This force transducer belongs to INM from Colombia and has been used to make the follow-up of the validity of the results to the 1 MN reference standard machine, therefore, it has calibrations made on a direct loading standard (PTB), thus demonstrating a long-term stable behavior.

The stability can be analyzed with the application of three evaluation criteria to test the instrument's stability. First, through the comparison between the maximal permitted error respect relative repeatability errors, where the results in all cases were satisfactory, remaining restricted by the maximum permissible error, to each load force applied. Second, there is an analysis development with a stability proof defined in the Colombian Technician Standard ISO 13528[1] as Figure 1 shows. This criterion consists of compare the difference of the average values of the deflections with rotation, between two different consecutive calibrations, with respect to 0.1 times the maximum error allowed. Finally, a metrological comparability test is applied, through the use of the normalized error estimator[2], wherever in all levels of applied load, the criterion was satisfied.

The before arguments support the statement about the sturdiness and instrumental stability of the C18 force transducer.

To minimize the uncertainty associated with the digital amplifier a high resolution, 1 ppm, indicators having good stability (HBM, type DMP 40 or DMP 41) should be used in the comparison. Participants will use their own indicators (HBM, type DMP 40 or DMP 41).

The pilot lab will send a calibrator device to avoid differences between indicators. At the same time, in order to check DMP 40 or DMP 41 indicating device, a BN 100A type HBM product calibrating device will be checked before and after the measurements (shown in Fig.2).

Each laboratory will use its own DMP40/DMP41 amplifier. They will be operated according to the following setup:

- Supply voltage: 110 / 220-240 V at 50/60 Hz
- Excitation voltage: 5 V at 225 Hz
- Measuring range: 2.5 mV/V
- Low-pass filter: 0.22 Hz Bessel[3]

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[1] ISO 13528 (2022). Statistical methods for use in proficiency testing by interlaboratory comparison

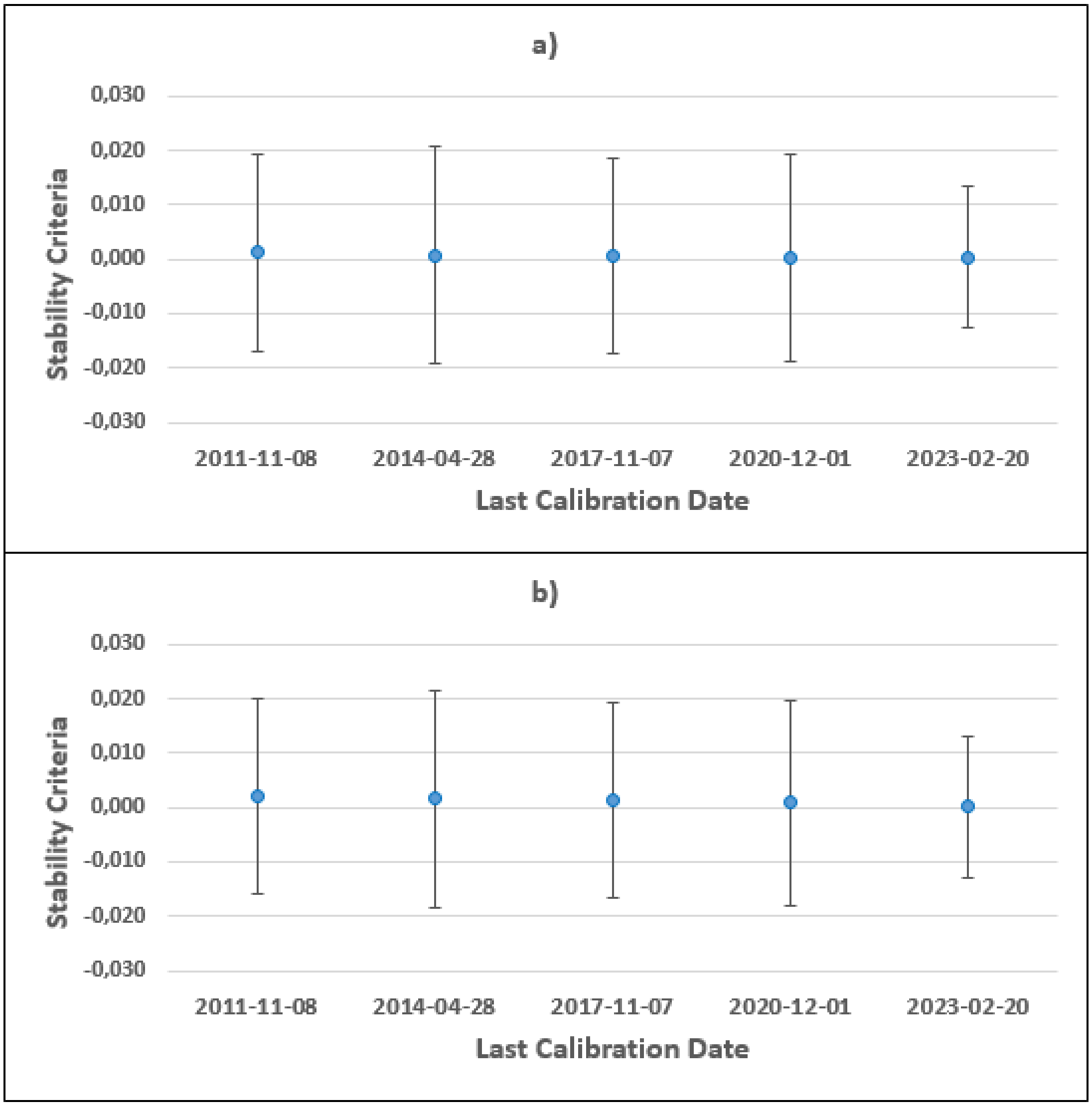
[2] ISO/IEC 17043 (2010) Conformity assessment—general requirements for proficiency testing.

[3] Depending on electrical and/or mechanical influences, another filter frequency could be chosen by the laboratory.

- Resolution: 0.000001 mV/V
- Measurement mode: Absolute
- Auto-calibration: On
- Measuring channel: Defined by each laboratory.

In case the laboratory does not have a DMP40 or similar, it is possible to use a MGCplus with ML38B card in similar configuration detailed above, additionally, you must record the results of the check made with the BN100 A in the spreadsheet intended for this purpose.

Figure 1. The blue points refer to the average value of the deflections with rotation for each calibration date. The results are respectively shown for the force applied: **a)** 500 kN. **b)** 1000 kN [4].



5. Preparation of measurement

After receiving the transducers, all devices will be kept at laboratory conditions. The following minimum time intervals are recommended before measurement:

- 3 days in the laboratory facilities.

[4] It should be noted that it was plotted in such a way that the limits that restrict the criterion are 1, however, they are omitted from the plot to highlight the variations between the differences of average measurements.

- 24 h in the laboratory where the measurements will be made, as close as possible to the machine to be used.
- 12 h mounted in the measurement position and connected to the digital amplifier to be used.

The measurement must be carried out without interruptions in each mounting position. Between the ending of one mounting position and the start of the next, it should not take more than 5 minutes. If this time is exceeded, it is recommended to carry out at least one additional preload without being recorded.

All readings must be recorded in the measurement protocol "*IC_SIM-1MN_Protocol.xslx*" spreadsheet "*raw_data*". The 0.22 Hz Bessel filter will be used unless there is a problem related to it, in which case a 0.1 Hz Bessel filter will be used instead. For this reason, it is recommended to pay special attention that the force is stable and there are no disturbances at least 30 s before recording the value, including the autocalibration of the amplifier.

The thrust piece will be mounted so that the mark made on it is aligned with the cable connector. When the transducer is rotated, clockwise viewed from above, the thrust piece will rotate with it to keep the mark aligned with the cable connector.

5.1. Environmental Conditions

Preferably, the measurements should be carried out at the ambient conditions given below:

- Temperature: (20.0 ± 1.0) °C
- Relative humidity: (50 ± 10) %RH

Note: Please, in case it is not possible to carry out the measurement at 20 ºC in your laboratory, indicate in which temperature you can measure.

The air temperature near the force transducer in ºC will be recorded with each measured value, excluding preloads. The relative humidity in % and the air pressure in hPa will be recorded at the beginning and at the end of measurements.

6. Measurement protocol

The procedure for performing the comparison measurements is described as two increasing series at each position. The results of the transfer force transducer will be evaluated in the range of 50% to 100%, that is 500 kN and 1000 kN.

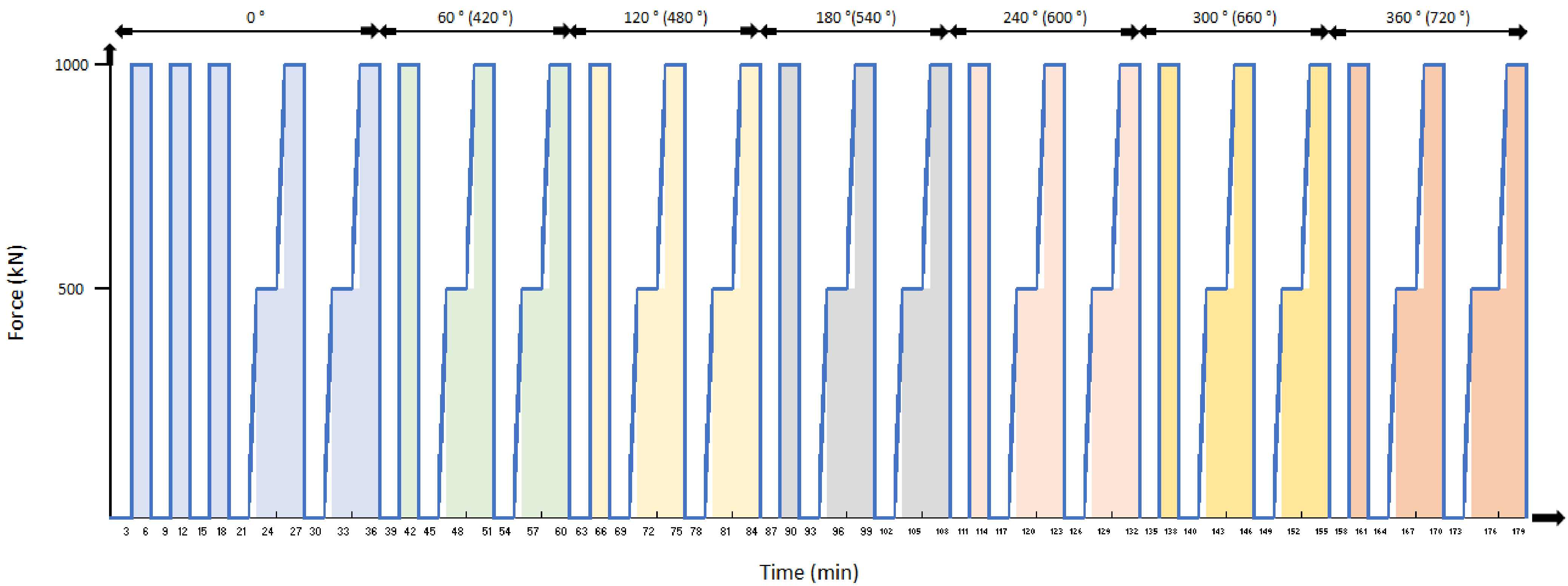
The following measurement schedule was agreed:

All pre-loadings and measurement series are carried out in the same time interval, which is three minutes between taking values. This time includes the time needed to change the load and its stabilization. The value is taken just before starting the load change, the comparison scheme can be seen in Table 5 and Figure 2.

Table 5. Measurement protocol

Position Degrees	Preload at 1000 kN	Series	Sequence kN
0	4	3	0, 500, 1000
60	1	1	0, 500, 1000
120	1	1	0, 500, 1000
180	1	1	0, 500, 1000
240	1	1	0, 500, 1000
300	1	1	0, 500, 1000
360	1	1	0, 500, 1000
420	1	1	0, 500, 1000
480	1	1	0, 500, 1000
540	1	1	0, 500, 1000
600	1	1	0, 500, 1000
660	1	1	0, 500, 1000
720	1	1	0, 500, 1000

Figure 2. Measurement sequence



To minimize the errors due to the non-axial components of deformation, the response of each force transducer is obtained at thirteen symmetrically distributed positions relative to the axis of the machine (0°, 60°, 120°, 180°, 240°, 300°, 360°, 420°, 480°, 540°, 600°, 660°, 720°). In order to get better results, prior to the start measurement cycle, the force transducer should be loaded with maximum test load three times at the 0° position.

Each force step is held for 6 minutes before taking the measurement. At 0° there are three preloads then two measurements. Then the sensor is rotated 60° and there is one preload and two measurements. Then this last step is repeated as many times as needed to achieve a total rotation of 720°. The total time needed, from before the preload to the end of all measurements is 9 hours 18 minutes.

The measurement data must be recorded raw in the "*IC_SIM-1MN_Protocol.xslx*" spreadsheet "*raw_data*" tab, which will be delivered by the pilot laboratory. A new tab can be added to this spreadsheet to consider correction factors that the laboratory deems necessary.

7. Measurements results, uncertainty and evaluation

Deflections are calculated from the readings. Each deflection value is defined as the reading at the force step minus the corresponding zero reading before applying the force step.

Deflection, mean value, repeatability, and reproducibility are calculated in the spreadsheet.

Measurement results are calculated from the original readings. The measurement result is the mean deflection calculated from the fourteen measured values in the thirteen mounting positions of the force transducer.

The measurement uncertainty is calculated for the mean deflection measured from the transducer and the used DMP40/DMP41.

The reference value (NIST) will be corrected linearly in time due to the temporal drift that is part of the loop in which each laboratory measures.

The uncertainties to be considered by each laboratory will be based on the Euramet cg/04 guide. The sources to consider will be:

- Laboratory CMC, as declared in Table 2.
- Reproducibility.
- Resolution.
- Amplifier. (Using a BN100A).
- Temperature.
- Long term drift. A rectangular distribution will be taken.

8. Reporting of Results

The results should be prepared in the sheet provided for this purpose and sent within 15 days, the data should be sent to Kevin Chesnutwood (NIST) with a report of the shipment to Alejandro Savarin and Ivan Betancur.

The report must contain at least:

- Details of participating laboratory,
- The date of the measurements,
- A detailed description of the measurement method and system used,
- The environmental conditions during the measurements,
  - Ambient temperature
  - Relative humidity
- Results of measurement; the measurement results shall be provided according to the excel file format.

References

- EURAMET. (2011). *Calibration Guide EURAMET/cg-04/v.02 (03/2011)-Uncertainty of Force Measurements.*
- IEC, I. /. (2010). *ISO / IEC 17043 "Conformity assessment — General requirements for proficiency testing".*
- ISO. (2022). *ISO 13528 (2022). Statistical methods for use in proficiency testing by interlaboratory comparison.*
- JCGM. (2008). *JCGM 100:2008(E) Guide to the Expression of Uncertainty in Measurement.*
- MRA-G-11, C. (2021). *Measurement comparisons in the CIPM MRA.*