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AN ANALYSIS OF THE PARTICIPATION OF INMETRO IN INTERLABORATORY COMPARISONS IN VIBRATION MEASUREMENTS

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Abstract:
This paper provides an overview of the participation of INMETRO on vibration interlaboratory comparisons along the last years and analyses the benefits of having an active participation in such activities.

Keywords: Vibration; key comparisons; supplementary comparisons; degrees of equivalence

1. INTRODUCTION

Interlaboratory Comparisons are used worldwide by the measurement community to obtain quantitative evidence to support the mutual recognition of measurement and calibration capabilities (CMCs). They are carried out at both CIPM Consultative Committee level and at Regional Metrology Organizations (RMO) level. Usually vibration key comparisons (KCs) are intended to compare the best measurement capabilities in a field, like for instance vibration or shock. Currently primary calibration methods which include laser interferometric calibrations of accelerometers and acceleration measuring chains are the main focus of such KCs. In order to restrict the time needed to conduct a KC to within one or two years, the number of participants have to be limited to about 10 or 12 participants maximum. Usually, the KCs try to have 2 or 3 participants from each RMO and allow further regional key comparisons to happen. Ideally, if the participants with smallest expanded uncertainties within a region represent the RMO at the CIPM KC level, then they can provide a link to further RMO KCs with minimal influence on the linking process. In addition, the RMOs can have supplementary comparisons to address the specific needs of the region.

2. DESCRIPTION OF THE WORK

This paper will provide an overview of the results obtained by INMETRO on recent interlaboratory comparisons and discuss the benefits of this process. Considerable improvements were achieved by the increase of interaction among researchers worldwide. KCs provide higher confidence on results, provide quantitative evidence to support mutual recognition, allow reduction of uncertainties, and consequently improvement of CMCs. In addition, technical visits to other laboratories during the transference of artifacts between participants, help interaction and technical exchange between the technical staff.

Comparisons within the vibration community, especially at CCAUV level, usually include challenges as for instance increase of frequency ranges that induce several critical analysis and lead to improvements on measurement systems and procedures. This process synchronizes the focus of the different participants distributed worldwide and facilitates technical exchange and dissemination of information between them.

The timeline correlating the reduction of expanded uncertainties with interlaboratory comparisons show that every single comparison provides valuable information, and this added knowledge creates the basis to support the improvement of measurement capabilities.

INMETRO has participated on the following CIPM key comparisons and RMO comparisons:

- Primary vibration calibration -
  CCAUV.V-K1.1 [1],
  CCAUV.V-K2 [2] and
  CCAUV.V-K5 [3]
- Primary shock calibration -
  CCAUV.V-K4 [4]
- Low-frequency primary vibration calibration -
  CCAUV.V-K3 [5]
- Low-frequency primary vibration calibration -
  AFRIMETS.AUV.V-K3 [6]
- Comparison vibration calibration -
  AFRIMETS.AUV.V-S3 [7]
- Primary vibration calibration -
  SIM.AUV.V-K1 [8]

3. RESULTS OBTAINED

The unilateral Degrees of Equivalence (DoE) between the results of a participant and the calculated Key Comparison Reference Value (KCRV) provide well-accepted evidence of the conformity of reported results. The DoE and its associated expanded uncertainty clearly show how close a result of an individual participant is to the KCRV and if the difference is covered by the claimed uncertainty. The DoEs are usually presented in tables and graphs covering the full range of the comparisons on their final reports. A smaller set of results obtained for some selected frequencies are presented in tables and in graphs on the KCDB. Outlier results are highlighted in the tables by the use of different formatting or background colors. They can also be easily identified in the graphs of DoEs if the difference (D_i) between an individual result and the KCRV is greater than its expanded uncertainty $U(D_i)$. Therefore, they are a valuable tool to evidence non-compliant results and measurement errors, helping participants to identify the need for reviewing their calibration process and possibly implementing some data corrections, system improvements or procedural adjustments.

The degrees of equivalence obtained by INMETRO for the Single Ended (SE) accelerometer in the vibration comparison CCAUV.V-K5, are shown in Figure 1,

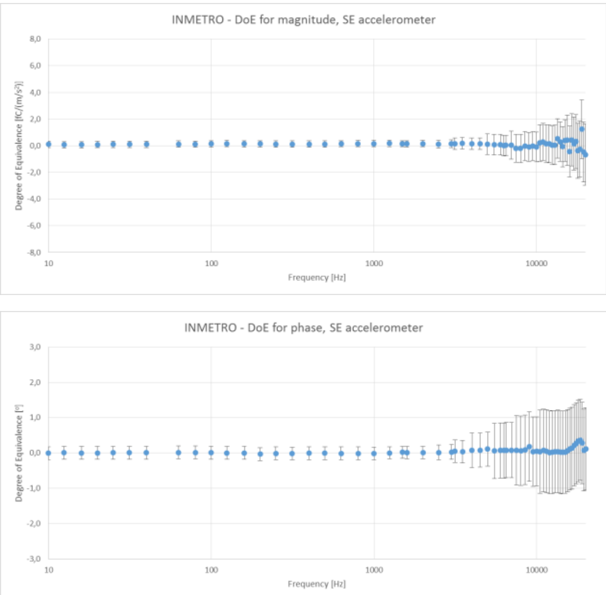

Figure 1: Degrees of Equivalence for magnitude and phase of sensitivity reported by INMETRO for the Single Ended (SE) accelerometer

It can be observed that the DoEs for magnitude of sensitivity and phase shift are in full compliance with the claimed uncertainties by INMETRO for the entire frequency range from 10 Hz up to 20 kHz. Therefore, these results were used as supporting evidence for the related CMCs published on the KCDB.

Table 1 presents the relative expanded uncertainty values reported by INMETRO for sensitivity magnitude at the reference frequency of 160 Hz along the last years. A considerable improvement of 2.5 times in uncertainty was achieved in approximately 20 years. This was possible not only due to the implementation of more refined calibration systems and measurement methods, but in great part to the experience earned along this period. The results obtained in all these KCs [1]-[3], [8] helped us to improve our confidence and to consequently reduce the associated measurement uncertainties

Table 1: History of the expanded uncertainties $U(S)$, k = 2, reported by INMETRO for sensitivity magnitude S at 160 Hz along the years

Comparison Identifier	**$U(S)$ @ 160 Hz**	**Year**
CCAUV.V-K5 [3]	0.20 %	2021
CCAUV.V-K2 [2]	0.24 %	2014
CCAUV.V-K1.1 [1]	0.24 %	2007
SIM.AUV.V-K1 [8]	0.50 %	2004

One important thing to be mentioned is that all KCs organized by the CCAUV have proposed challenges to the vibration community. The scope of the KCs has increased considerably since the first one, demanding for several improvements in terms of calibration methods and measuring systems. For instance, CCAUV.V-K1 [9] started covering only magnitude of accelerometers´ sensitivity for the limited frequency range from 40 Hz to 5 kHz. Even though there were severe difficulties for stating acceptable equivalence between the reported results by the participants at higher frequencies.

The level of agreement achieved was much better for the next CIPM vibration KC, CCAUV.V-K2 [2]. This second one covered both magnitude and phase of accelerometers´ sensitivity in the frequency broader range from 10 Hz up to 10 kHz.

The latest vibration CIPM KC, CCAUV.V-K5 [3], could cover an even broader measuring range, including magnitude and phase of sensitivity from 10 Hz up to 20 kHz. This was possible because most participants were already using the sine-approximation method (method 3, in ISO 16063-11) [10] and additional precautions were considered in the technical protocol [11] of this comparison. In order to improve the level of comparability and the immunity to differences on mounting conditions by the different participants, the single-ended accelerometer was circulated already screw mounted on a mechanical adapter with a laser-reflective polished surface. This was made aiming to provide a more homogeneous measuring condition to all participants and obtain higher immunity from the different vibration exciters used by them.

Some later studies have evidenced that the adaptor used was not as stiff as expected [12], but despite of this the results obtained allowed the calculation of a KCRV and the DoEs for all participants. Therefore, this KC successfully served for its purpose to provide quantitative evidence to support measuring and calibration capabilities (CMCs) of the participants.

All the lessons learned from these past KCs will certainly be considered to format the next CCAUV vibration KCs. In addition, they provide helpful information to allow improvement of each participant´s calibration system and procedures.

Along this period, many papers have been published by NMI researchers driven by the KCs. The technical exchange between laboratories have increased significantly and solutions have been proposed to address the limiting factors for good compliance between results.

Some important examples are the discussions and studies about the influence of input impedance on the calibration of charge amplifiers [14], [15]; the influence of different materials and the stiffness of vibration exciters' moving table at high frequencies [16]-[19], and the influence of local gravity on low frequency calibration results [20], [21]. Counteractions to address such difficulties have been proposed and they have contributed to the improvement of the comparability level achievable by current KCs.

4. SUMMARY

Interlaboratory comparisons are the preferred way to obtain a direct supporting evidence for calibration certificates and measurement capabilities. They provide the quantitative basis for mutual recognition of CMCs between laboratories in different fields. This happens both at the level of NMIs and secondary accredited laboratories. The authors address the importance of participating in this kind of activities, which provide a very helpful way to analysis the level of historical evolution of measuring capabilities. The experience from the vibration laboratory of INMETRO in recent comparisons was very positive in all aspects.

Considerable improvement was achieved in terms of knowledge, measurement capability and recognition due to our participation in comparisons. Many of the developments and improvements implemented in our calibration systems and methods were motivated by the upcoming comparisons in which we had agreed to participate. Considering that the weighted mean method has been used to calculate the KCRV for recent CCAUV KCs, we have identified the importance of reporting smaller uncertainties and this goal is being constantly pursued. The capability to cover the full scope of a key comparison and holding the capability to provide calibration results with reduced uncertainties is very important for maintaining a proper regional representation level at CIPM KCs and for the best linking of subsequent regional KCs.

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