

REALIZATION AND RESULTS OF A DKD INTERLABORATORY COMPARISON REGARDING THE MEASURAND ACCELERATION

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Abstract: The standard ISO/IEC 17025:2005 [1] demands from calibration laboratories that the ‘participation in a suitable programme of interlaboratory comparisons is required where possible’. In 2009, the working group of the German DKD concerned with acceleration and vibration decided to start such an interlaboratory comparison programme regarding the measurand acceleration and related quantities. This paper presents the set-up and organization as well as some combined results of this programme.

Keywords: accreditation, acceleration, interlaboratory comparison

1. INTRODUCTION

Most of the German calibration laboratories accredited by the accreditation body DAkkS (successor of the former DKD) participate in the work of the so-called DKD working groups that work on practical technical rules for calibration methods according to existing ISO standards or work on technical rules for new calibration methods that shall be standardized in the future. In 2009, the DKD working group for acceleration decided to start an interlaboratory comparison programme regarding the measurand acceleration. Nine of the 11 calibration laboratories currently accredited for the measurand acceleration took part in this programme. Additionally, one non-accredited calibration laboratory from the public service decided to participate in this programme.

The interlaboratory comparison programme was set up in a star-type topology with a pilot laboratory as the central coordinator of the programme. It was the task of the pilot laboratory to coordinate the schedule of the measurement programme and to calibrate the set of reference accelerometers every time before they were sent to one of the other participating laboratories. The recalibrations were carried out in order to assure that the reference accelerometers have not been damaged during the last shipment and to reveal any drifting of the reference values during the course of the programme.

Because one of the participating laboratories – SPEKTRA – is accredited for the primary calibration of accelerometers according ISO 16063-11 and could provide

the smallest measurement uncertainty of all participants, it was chosen to be the pilot laboratory. Figure 1 shows the high-frequency primary calibration system of the pilot laboratory used for the monitoring purposes, which allowed fast and precise primary calibrations. All other participating calibration laboratories performed secondary calibrations according to ISO 16063-21. The results of the participants including the initial measurements of the pilot laboratory were sent to PTB for evaluation.

In order to provide traceability of all results to the German National Metrology Institute PTB, the reference standards were additionally calibrated by PTB at the beginning and at the end of the programme according to ISO 16063-11. Furthermore, PTB performed the analysis of the whole comparison program according to the common rules.

The schedule of the interlaboratory comparison was kept tight since the working group had the goal to accomplish the whole measurement programme within less than one year. This means that the cycle time between calibrations at two participating laboratories including the intermediate calibration in the pilot laboratory was about one month. Since the shipping time from and to the pilot laboratory was included in this cycle time, too, all participating laboratories had to work quickly after receiving the reference devices. In this regard, the time-consuming primary calibration was a special challenge for the pilot laboratory SPEKTRA. For each monitoring cycle, calibrations at about 800 frequency points had to be performed adding up to a total of 8000 frequency points for the monitoring measurements only. Additionally, a lot of effort was spent on preceding measurements in order to select the best reference devices. However, the measurement programme could finally be accomplished within an 11 months period from September 2010 to July 2011.



Fig. 1. High-frequency primary calibration system at the SPEKTRA calibration laboratory

The reference accelerometers were chosen to comply with the following criteria:

- they have to be well known as stable reference accelerometers
- the combination of all accelerometers have to cover the frequency range from 0.2 Hz to 10 kHz
- IEPE, charge and VC type accelerometers have to be included in order to cover the most typical types of accelerometers
- calibrations with the sensitive accelerometer axis in vertical and in horizontal direction have to be performed

According to these criteria, the following accelerometers were chosen:

- PCB J353B01 (IEPE type) for the range 5 Hz to 10 kHz
- Brüel & Kjaer 8305-001 (CHARGE type) for the range 10 Hz to 10 kHz
- PCB 3701G2FA3G with supply (VC type) for the range 0.2 Hz to 200 Hz

Furthermore, the following signal conditioners were chosen:

- Brüel & Kjaer 2692 (Nexus) CHARGE amplifier for the range 0.2 Hz to 50 kHz with 1 pC, 100 pC, 10000 pC
- PCB 480C05 CH1 voltage amplifier for the range 0.2 Hz to 50 kHz at 100 mV
- PCB 480C05 CH2 IEPE amplifier for the range 0.2 Hz to 50 kHz at 100 mV

2. RESULTS FROM THE PILOT LABORATORY

It was the main task of the pilot laboratory SPEKTRA to calibrate the reference devices after they were sent back from the participating laboratories and to monitor any changes of the properties of the devices. For all reference devices, the complex transfer coefficient (magnitude and phase) was determined. The primary calibration of each accelerometer was performed at four positions around the

accelerometer. At each position, 38 frequency points were measured. The signal conditioners were calibrated at 55 frequency points for each loading condition.

It turned out that all reference devices had very stable properties during the ten months of the test programme although they all had to withstand the shipping conditions and were handled by a lot of different operators.

Fig. 2 for example shows the standard deviation of all ten accelerometer calibrations in the pilot laboratory over frequency. The standard deviation over the main frequency range is remarkably low compared to the nominal measurement uncertainty of 0.5 % of the SPEKTRA primary calibration system as certified by the German accreditation body DAkkS. Only at the edges of the respective frequency ranges of the sensors the standard deviation is slightly increased due to properties of the accelerometer and mechanical uncertainty contributions that typically occur at these frequencies. In addition, the relative deviation of the sensitivity at the reference frequency point compared to the mean value of all calibrations stayed within a range of 0.1%.

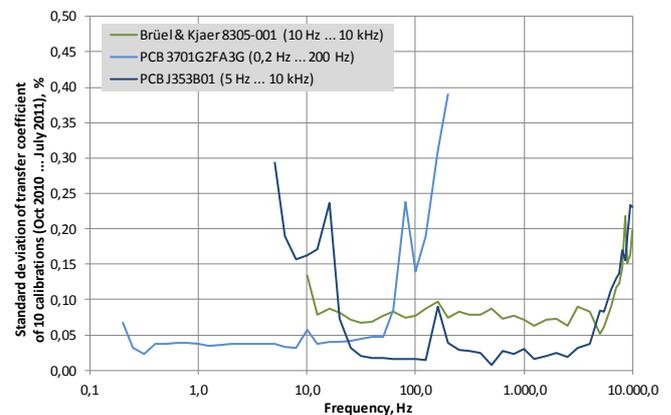


Fig. 2. Comparison of accelerometers – standard deviation of 10 monitoring calibrations at the pilot laboratory

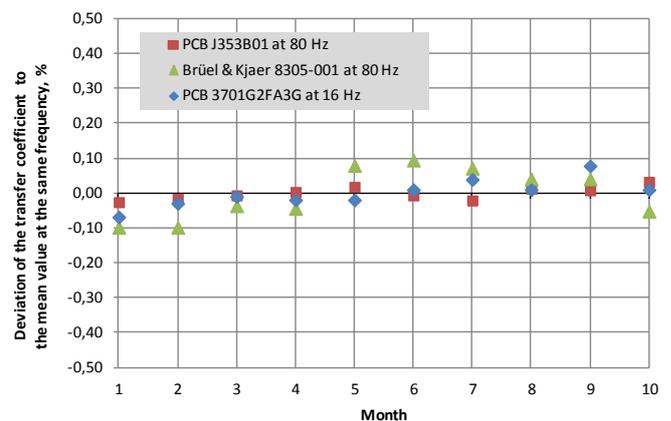


Fig. 3. Comparison of accelerometers – relative deviation of 10 monitoring calibrations compared to the mean value at the frequencies 16 Hz or 80 Hz, respectively

For the signal conditioners, even calibration results with lower standard deviations could be expected since pure electrical measurements allow much lower measurement

uncertainties. In fact deviations stayed below 0.05 % ($f < 10$ kHz, see Fig. 4. and Fig. 5). The only exception was the charge amplifier at very low input amplitudes of 1 pC, where noise from external sources and from the cables becomes more significant. But again, the deviations were small compared to the nominal measurement uncertainty of the calibration system (0.2% in the main frequency range).

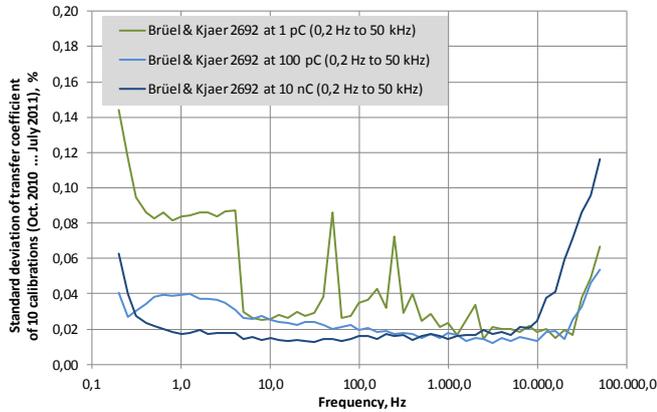


Fig. 4. Comparison of charge amplifiers – standard deviation of 10 monitoring calibrations at the pilot laboratory

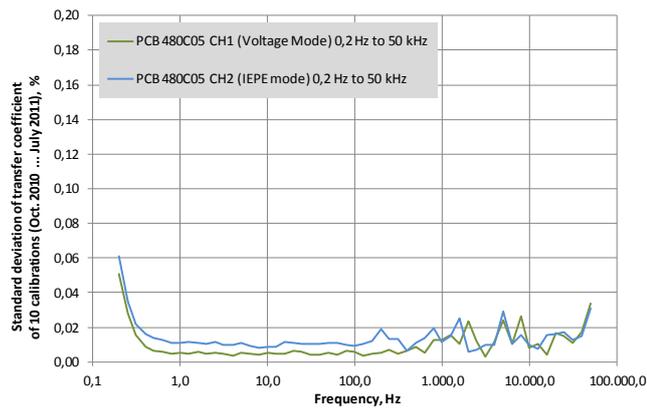


Fig. 5. Comparison of voltage / IEPE amplifiers – standard deviation of 10 monitoring calibrations at the pilot laboratory

OVERVIEW OF THE COMPARISON RESULTS

For the evaluation of the individual results of the accredited (and one non-accredited) laboratories, the deviation from the PTB calibration results was considered. This means, for the magnitude results of the sensitivity with an attributed relative uncertainty, the parameter

$$E_{n,mag} = \frac{|S_{Lab} - S_{PTB}|}{\sqrt{u_{m,Lab}^2 \cdot S_{Lab}^2 + u_{m,PTB}^2 \cdot S_{PTB}^2}} \quad (1)$$

was calculated. For the phase results of the complex sensitivity, the respective parameter is

$$E_{n,phase} = \frac{|\varphi_{Lab} - \varphi_{PTB}|}{\sqrt{u_{\varphi,Lab}^2 + u_{\varphi,PTB}^2}} \quad (2)$$

In both cases, this well known E_n value is supposed to be below (or equal) 1.0 to indicate a comparison measurement

deviation covered by the associated measurement uncertainty.

Figure 6 and 7 give a graphical representation of the statistics over this E_n criterion. The top sections of the columns (in red) indicate the number of measurements, which were not covered by the associated measurement uncertainty. Looking at the bars one may draw some conclusions:

- The general quality of the acceleration calibration system in Germany is in a good shape. This is valid for sensors as well as for the conditioning amplifiers.
- The number of phase measurements is smaller than the number of magnitude measurements, which represents the situation in the accredited ranges.
- Two challenges seem to exist, i.e. the phase calibration of charge amplifiers (c.f. Nexus 0.1) and the calibration of ICP amplifiers with the supply current switched on (c.f. PCB 480C05 CH2).

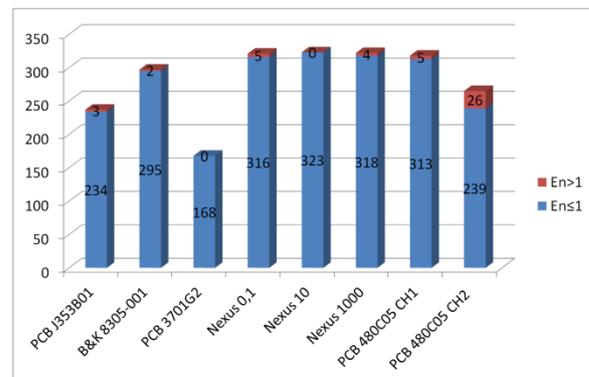


Fig. 6. Statistics of the E_n values over all measurements for the magnitude of the complex sensitivity

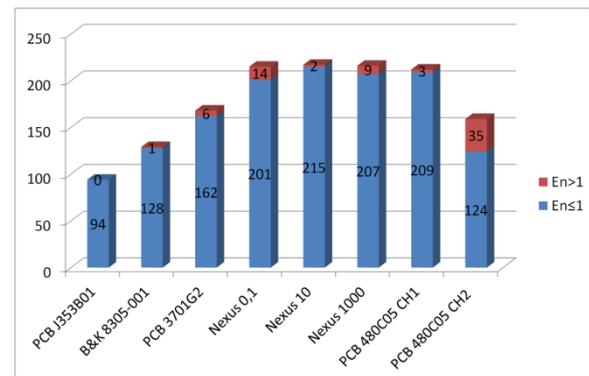


Fig. 7. Statistics of the E_n values over all measurements for the phase of the complex sensitivity

From the data it appears that the deficiencies for the calibration of ICP amplifiers with supply-currents switched on are limited to the frequency area below 10 Hz. At these frequencies complications arise if a capacitance is used to decouple the bias voltage of the input from the data acquisition system. For low frequencies the decoupling capacity need to be quite high and consequently requires a long charge or discharge time

constant. Depending on the details of the measurement methodology this may be in the order of several seconds for each change of frequency. If the calibration procedure does not take care of this effect, systematic deviations have to be expected. A reliable method to circumvent these decoupling issues is to use a AD-converter of sufficient resolution, preferably 24 bit, in a DC-mode sampling. This allows to reliably resolve the small nominal sine oscillation on top of a large bias voltage. For the phase calibration of charge amplifiers with small input charge (0,1 pC) the deviations probably have to be attributed to an underestimation of the influence of the electrical noise on the input. In these cases the accredited relative measurement uncertainty is no longer applicable but has to be recalculated with respect to the reduced signal to noise ratio.

5. SUMMARY

The presented national intercomparison of accredited laboratories for acceleration and vibration shows the high level of competence provided by the German accreditation system. The practical process proofed the feasibility to perform such work in a short time with the means available within the community of laboratories complemented by the national metrology institute in order to provide the reference value and the independent evaluation.

The outcome of the comparison confirmed the general high quality of the area of acceleration and vibration metrology in Germany but also pointed at some spots where further development may be beneficial.

The re-established DKD with its technical working groups will give the forum for the further improvements concerning these and other topics.

6. REFERENCES

- [1] General requirements for the competence of testing and calibration laboratories; ISO / IEC 17025:2005