IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference
11 – 13 October 2022, Cavtat-Dubrovnik, Croatia

RECENT STUDY IN PRIMARY ACCELEROMETER CALIBRATION - PROGRESS, DEVELOPMENT AND LESSONS LEARNED

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Abstract:

Primary calibration of accelerometers by laser interferometry has been performed for more than 50 years. It was made possible by the advent of the commercial He-Ne lasers in the 1960ties. During the last 20 years the progress in digital signal treatment has made it available for most interested laboratories.

However, these huge progresses have merely reduced but not removed some basic problems.

- The quality and basic parameters of the exciter systems
- The influence from the mechanical setup on the accelerometer and thereby on the measurement results.

This paper describes several topics and considerations found relevant for primary calibration of accelerometers, following recent international intercomparisons and progress in the calibration grade vibration exciter system design.

Keywords: Primary accelerometer calibration; calibration grade vibration exciter; relative motion; comparison measurements; Finite Element Analysis (FEA)

1. INTRODUCTION

Where the ISO 16063-11:1999 method 3 sine approximation method describes recommended instrumentation, frequency ranges, data acquisition and uncertainty components to be considered, the standard provides little details on the actual mechanical setup needed to perform properly comparable measurement results of Back-To-Back (BTB) as well as Single-End (SE) reference standard vibration transducers at NMI level.

In addition to and following a number of papers and presentations on this topic e.g. prepared at INMETRO [1] and PTB [2], this paper aims to condense recent experiences and findings at DPLA reducing dispersion between different exciter and laboratory setups to a *very minimum* as needed when performing NMI level measurements within the field of vibration. We will also provide FEA on different mechanical SE adaptor designs and an example of a modern calibration grade exciter design, with regards to relative motion and the apparent resonance frequency of the system to be calibrated, along with a number of corresponding measurements found relevant.

2. CONSIDERATIONS FOLLOWING RECENT CCAUV AND EURAMET RMO COMPARISONS

In recent Key Comparisons (KC) following the basic principles concluded in articles [1] and [2] and using fixed mechanical adaptor sent along with KC SE unit, a good correspondence in general is found on both magnitude and phase in the entire frequency range from 10 Hz to 20 kHz for both SE and BTB units. Considering the different apparatus and mechanical setups between participating laboratories this is a much-desired outcome now facilitating much needed Calibration and Measurement Capabilities (CMC) > 10kHz with accreditation bodies as in the Key Comparison Database (KCDB).

The BTB measurement is not influenced to same extent by difference in exciter armature material, as coupling from reflecting surface to accelerometer element can be considered rigid. Furthermore, coupling from BTB exciter mounting to the reflecting top surface is through accelerometer housing thus cannot be considered rigid. This means any difference in armature density [kg m^{-3}], Young's modulus [GPa] and mass [kg] will have little or insignificant influence on calibration result.

A SE measurement using fixed adaptor made from e.g., steel is normally only slightly influenced by exciter armature characteristics, as the DUT will have rigid coupling to the adaptor, and the mechanical transmission from reflecting surface to accelerometer element will be through the SE adaptor, thus material dependence will be reduced to the adaptor material used.

Details concerning any minor differences still found will be relevant to evaluate, and the apparent resonance of entire system including DUT, stud, armature and adaptor if used, will be influenced to some extent by difference in weight and coupling.

3. FUTURE PRIMARY MEASUREMENTS ON SINGLE ENDED (SE) AND BACK-TO-BACK (BTB) TRANSDUCERS

- Exciter must be optional (according to ISO16063-11 method 3) – This is only possible if proper conclusions from the results of section 2 have been disseminated and agreed by all relevant laboratories that has CMCs in the KCDB and databases from local accreditations.
- Adaptor should not be needed to send along for interlaboratory comparisons (ILC) – *Should be standardised through ISO and adopted in local relevant standards.* (The ISO16063-11 is to be revised).

FEA on the used SE adaptor design and on a suggested improved design are shown in Figure 1 to Figure 7.

The results are not including the load of the transducer nor the properties of the exciter mounting surface.

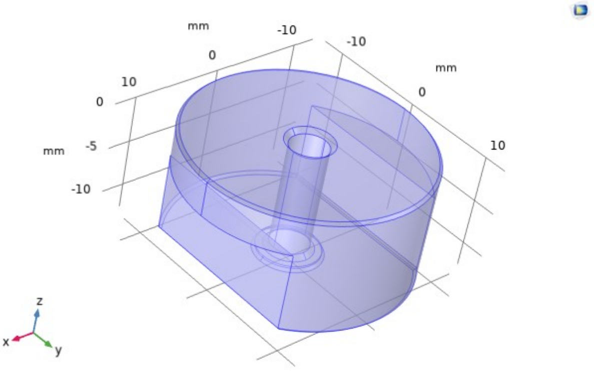

Figure 1. Adaptor used in key comparison.

Transfer function H is defined as:

$$H = \frac{\text{Measured acceleration at top}}{\text{Applied acceleration at bottom}}.$$

The applied acceleration is 1 m/s^2 in the z-direction. The measured acceleration at the top surface varies depending on the distance from the centre and whether it is on the line cutting through the “ears” or perpendicular to that.

The difference in the transfer function over the frequency range is not important as the laser measurement is on the top surface of the adaptor.

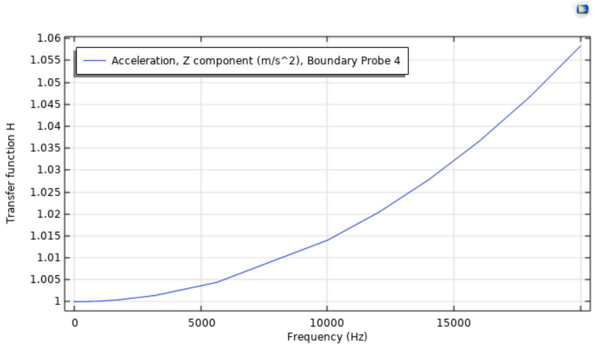

Figure 2. Transfer function 4 mm from the centre

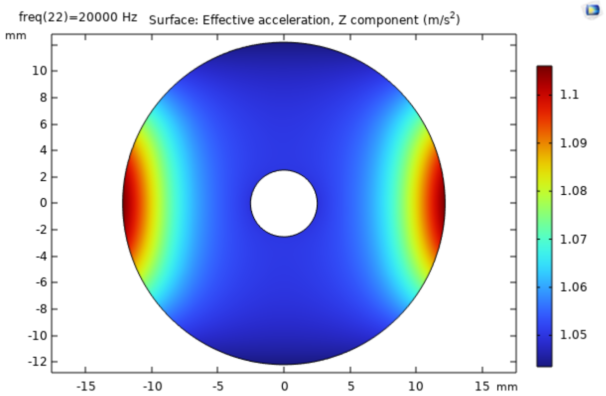

Figure 3. Acceleration pattern on the top surface

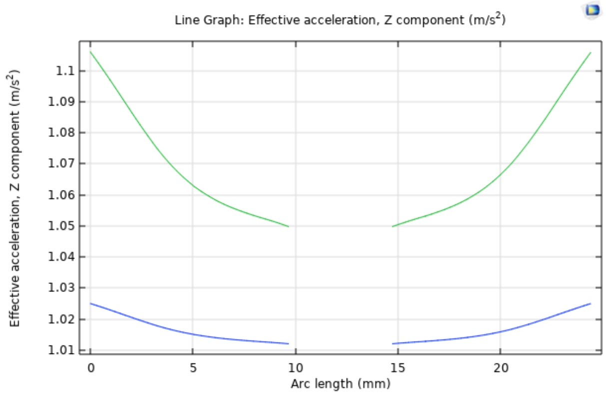

Figure 4. Acceleration along the line through the "ears" at 10 and 20 kHz (blue and green).

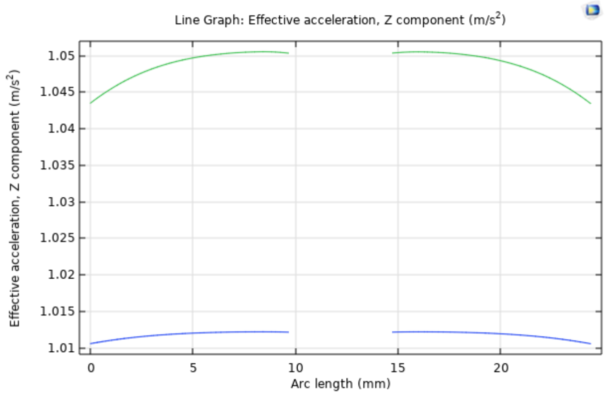

Figure 5. Acceleration along the line perpendicular to the line through the "ears" at 10 and 20 kHz (blue and green).

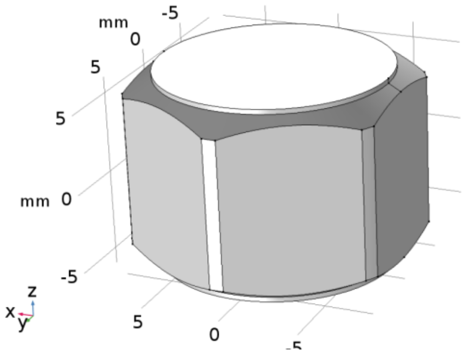

Figure 6. Suggested new adaptor design (10/32” or ¼” thread is added later).

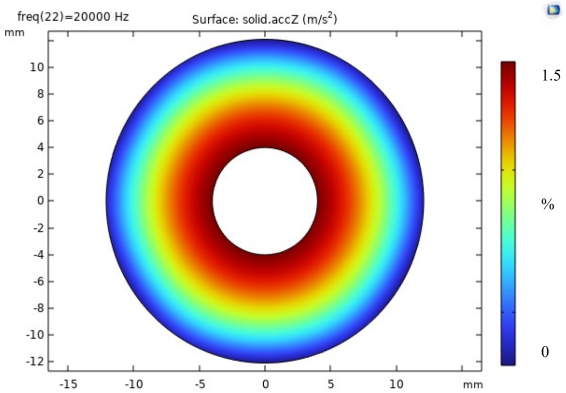

Figure 7. Acceleration pattern on the top surface at 20 kHz percent difference

It is clearly seen in Figure 7 that the influence of the actual angle of measurement is removed by the new design. The only important parameter is the distance from the centre. At 20 kHz that amounts to approximately 0.15 % per mm.

4. CONSIDERATIONS ON MODERN HIGH FREQUENCY (HF) EXCITER DESIGN FOR ACCELEROMETER LASER CALIBRATION

Considering above mentioned the requirements of an ideal calibration grade exciter will be:

- Linear motion along one axis with pure sine signals in the desired frequency range
- No impact on accelerometer sensitivity (temperature, magnetic fields, coupling, base strain, ...)
- Ease of use → no operator contribution to the uncertainty (accelerometer weight, centre of gravity, mounting conditions, ...)

Physical limitation leads to deviations from this ideal – one can only try to get as close as possible by optimising the main parts of a calibration exciter. Since the electrodynamic drive principle is the best for the HF application we should care about the moving element (armature) and the guidance (bearing) of the armature.

Considerations regarding the armature

The main requirement “no resonances in the desired frequency range” shows after design considerations the importance of the armature material. For HF applications the factor Young’s modulus / density (basically the speed of sound $c = \sqrt{\frac{E}{\rho}}$) needs to be as high as possible which leads to either beryllium or ceramics. Since beryllium “should be banned wherever possible” (REACH) the usage of ceramics is mandatory.

Considerations regarding the bearing of the armature

The main requirement “linear single axis motion without friction or stick-slip effects” leads to two possible solutions:

- Air bearing
- Flexure bearing

What are the main properties?

Air bearing pro:

- Armature is decoupled from the rest of the exciter → only one spring (air) mass (armature) system leads to low cross motions (typical 5 % outside the main resonance at approx. 100 Hz – 200 Hz)

Air bearing con:

- Compensation of DUT weight for retaining the zero-position necessary [rubber bands (handling) or Lorentz lifting Coil (heating of armature, lower resonance frequency)]
- Limited cross force of approx. 2 N
- Horizontal operation practically impossible
- Sensitive to armature heating (air gap changes)
- Requirement of clean compressed air supply
- Armature cooling practically impossible

Flexure bearing pro:

- No DUT weight compensation needed (DUT mass=300 g changes zero position < 1 mm) → ease of use / no heating of armature
- High cross force: > 30 N
- Horizontal operation possible
- Cooling possible (approx. double force/acceleration with same temperature rise)

Flexure bearing challenge:

- The coupling of the armature to the rest of the exciter leads to a tradeoff between robustness vs. cross motion. Serious design considerations and trials led to a compromise that fulfils ISO 16063-11 requirements (see calibration results) with significant advantages in terms of usability compared to an air bearing.

The exciter developed following these considerations is shown in Fig. 8.

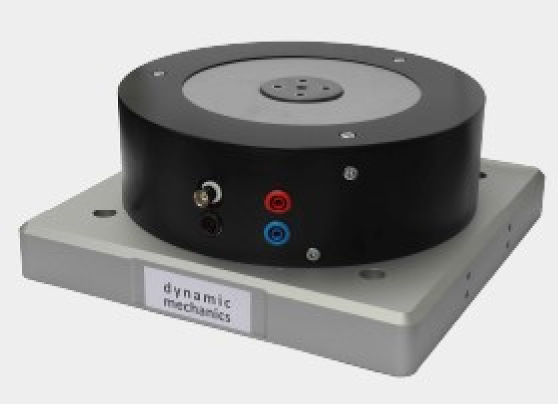

Figure 8. Exciter with ceramic table, built-in reference accelerometer and spring guidance

Figure 9 shows the cross-motion performance which is comparable to air bearing exciters.

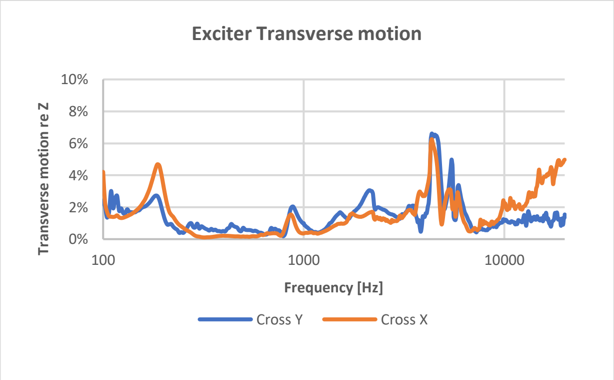

Figure 9. Exciter cross motion 100 to 20000 Hz.

Figure 10 and Figure 11 show results of primary laser calibrations on the two different exciters. The difference is no larger than the uncertainties in most cases. The deviation of about 0.6 % at 8 kHz for the single ended transducer is probably due to the slightly different transverse resonance which results from different mounting conditions. This problem has been described in the international comparison reports.

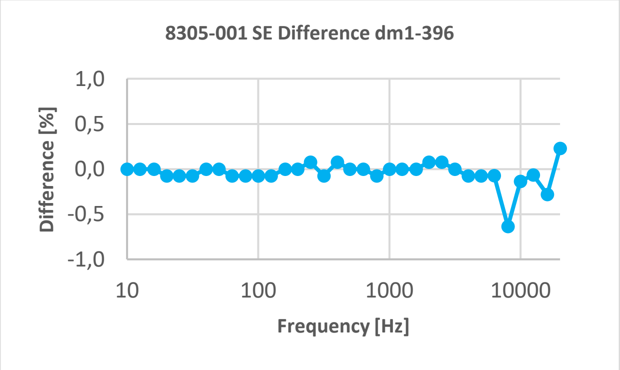

Figure 10. Difference laser calibration between a spring controlled and an air bearing exciter on a single ended reference transducer.

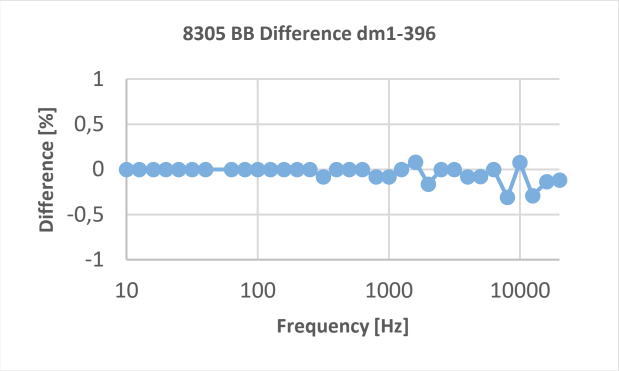

Figure 11. Difference in laser calibration between a spring controlled and an air bearing exciter on a Back-to-back reference transducer.

Other disturbing parameters like deformation of the table surface and the magnetic field gradient have been measured and are fully acceptable.

5. SUMMARY

This study has helped summarize years of experience at DPLA with recent findings though KC and exercises including testing of new types of exciters, and to provide a better understanding of what is needed in general to perform primary calibration at NMI level. We believe new guidelines though standardisation on this topic is needed to improve calibration capabilities across NMIs and on how to choose laboratory equipment.

6. REFERENCES

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