

CALIBRATION OF LASER VIBROMETER STANDARDS ACCORDING TO ISO 16063-41

Dr.-Ing. Uwe Buehn¹, Dr.-Ing. Holger Nicklich², Dr.-Ing. Heinz Weissing³, Dr.-Ing. Georg Siegmund⁴

¹ SPEKTRA GmbH, Dresden, Germany, Uwe.Buehn@spektra-dresden.de
² SPEKTRA GmbH, Dresden, Germany, Holger.Nicklich@spektra-dresden.de
³ SPEKTRA GmbH, Dresden, Germany, HWeissing@t-online.de
⁴ Polytec GmbH, Waldbronn, Germany, G.Siegmund@polytec.de

Abstract: All users of primary calibration systems - excepting the national metrological institutes - are under obligation to trace back their reference standards – their laser vibrometer standards – to their respective national standard if they intend to apply for (or maintain) accreditation or to strive for a very low measuring uncertainty for other reasons [5]. A calibration method will be described in this paper that has been used by the accredited laboratory of SPEKTRA for calibrating a greater number of laser vibrometer standards. All these calibrations proved the reliability and the very low measurement uncertainty of this method.

Keywords: calibration, laser vibrometer standard, primary.

CALIBRATION SYSTEMS

Vibration sensors are usually calibrated by means of calibration systems that use the method of comparison based on ISO 16063-21, also called **secondary calibration**. The basic principle of this method is to make a rigid mechanical connection of the sensor under test (object of calibration) to the reference standard and expose both simultaneously to the same acceleration. The wanted transfer coefficient of the sensor under test is obtained from the ratio of the electric output signals of the sensor under test and the reference standard. Fig. 1 shows the photograph of such a system.

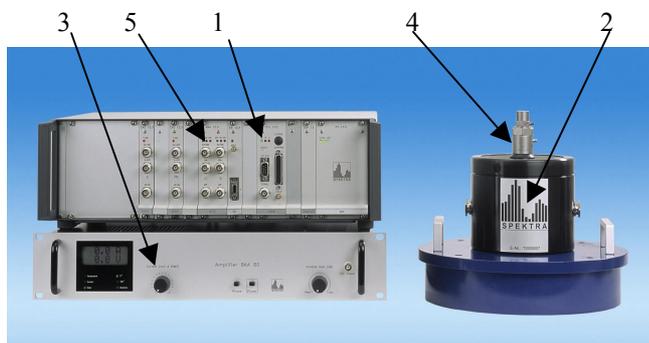


Fig. 1. Secondary calibration system CS18 MF

The system is made up of the following components:

- Vibration generator (1)
- Vibration exciter (2) with power amplifier (3)

- Back-to-back reference standard (4)
- Signal conditioning and data acquisition unit for reference standard and device under test (5)
- Vibration Control Unit for measurement, control and user software interface.

Prior to carrying out any comparison measurement, the reference standard, in most cases a back-to-back sensor, must be calibrated by an accredited calibration laboratory or the respective national metrological institute (in Germany: PTB).

In addition to the systems mentioned so far, so-called **primary calibration systems** have been available on the international market for a number of years [3]. In such systems, the physical quantity **acceleration** is measured by interferometry using the Doppler effect. Fig. 2 shows the photograph of such a primary calibration system for the frequency range of 5 Hz to 20 kHz.

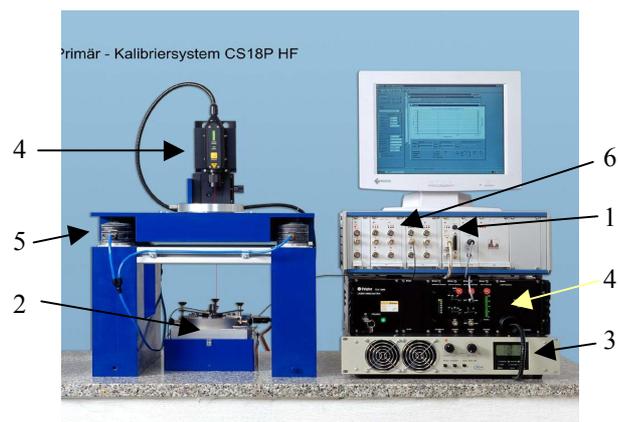


Fig. 2. Primary Calibration System CS18P-HF for frequency range 5 Hz up to 20 kHz.

It is made up of the following components:

- Vibration generator (1),
- Vibration exciter (2) with power amplifier (3),
- Laser interferometer (4) with vibration-isolating foundation (5),
- Signal conditioning and data acquisition (6) unit for the device under test
- Vibration Control Unit for measurement, control and user software interface

In addition to the main task of calibrating sensors, most of the primary and secondary systems also allow the physical quantity acceleration to be generated and measured with very low uncertainty.

While in the secondary calibration systems used so far, a high-precision **accelerometer standard** calibrated by the relevant national metrological institute is used as a reference standard, in primary systems a suitable **vibrometer standard** takes this task. As a consequence, all users of primary calibration systems (with the exception of the national metrological institutes themselves) are under obligation to trace back their reference standard – the vibrometer standard – to the national standard if they intend to apply for or maintain accreditation or strive for a very low measurement uncertainty for other reasons.

Thus the vibrometer will be the **object of calibration** and its calibration will be a new **calibration task**, regardless whether the procedure of calibration is carried out in a national metrology institute or in an accredited calibration laboratory.

As early as in 2004, the Working Group Acceleration at the German Calibration Service (DKD) dealt with this problem and issued the DKD-Richtlinie DKD-R 3-1 / Blatt 4 [1], a guide to primary calibration including the calibration of vibrometer standards. Shortly after, a draft of ISO standard 16063-41 [2] was worked out and has been circulated in the respective ISO committee.

While the draft of ISO 16063-41 [2] describes all possible methods for the solution of the calibration issue, which is very helpful to national metrology institutes, the guide [1] concentrates on one particular method that is described there in chapter 6 and Fig. 2 and is based on the sine approximation method referred to as method 3 in the well-known standard ISO 16063-11. Meanwhile this method has been employed and tested several times with excellent results that will be presented in this lecture.

Before dealing with the measuring system and the calibration results, let us take a look at the **laser vibrometer standard** in some detail.

LASER VIBROMETER STANDARD

The laser vibrometer used as a reference standard consists of the **laser optics unit** and the **signal processing unit** [6]. The laser optics unit uses optical interferometry to trace back the mechanical displacement and / or velocity directly to the wavelength λ of the laser light according to equations

$$\Delta\varphi(t) = \frac{4\pi}{\lambda} s(t) \quad (1)$$

and

$$\Delta f(t) = \frac{2}{\lambda} v(t) \quad (2)$$

where

$\Delta f(t)$	instantaneous value of frequency
$\Delta\varphi(t)$	instantaneous value of phase deviation
$v(t)$	instantaneous value of velocity
$s(t)$	instantaneous value of displacement

Since the wavelength of the laser light has a very small uncertainty, the measurement uncertainty of the electrical quantities $\Delta f(t)$ and $\Delta\varphi(t)$ at the output of the laser optics is very small, too.

The application of a Heterodyne-Interferometer has proved to be a good solution, since in this case the quantities $\Delta f(t)$ and $\Delta\varphi(t)$ are available in the form of modulation signals riding on a high-frequency carrier signal. As a consequence, any nonlinearities of the photo detector have virtually no influence on the relevant parameters of the Doppler signal.

On the other hand, if a Homodyne-Interferometer is used, additional precautions should be taken to maintain the linear operation of the photo detector if you are faced with changing reflection properties. Signal distortions of the homodyne signal cause measurement errors that grow with dropping displacement amplitude.

When measuring the magnitude of a straight vibration quantity (e.g. displacement), the measurement uncertainty is determined almost exclusively by the signal processing unit which reconstructs the instantaneous values of velocity or displacement from the quantities $\Delta f(t)$ or $\Delta\varphi(t)$.

Common laser vibrometers using analogue signal processing methods are on principle affected by linearity and drift errors. Usually they cannot be used as a reference measuring system. However, using available state-of-the-art technologies of digital signal processing, it is possible to demodulate the Doppler signal with highest precision by purely numerical methods, so avoiding any influence of drift [6]. Such methods are used in reference measuring systems and described in the standards for primary calibration.

At the German metrology institute (PTB), a commercial Laser vibrometer that employs method 3 according to ISO 16063-11 for the numerical demodulation of the Doppler signal has been tested with success. As a result of this investigation, it has been proved that this type of laser vibrometer can be used as a laser vibrometer standard in primary calibration systems.

As for the final processing of signals, it is advisable to process the demodulated digital measuring signals by an external computer. To this end, the laser vibrometer standard should have a suitable data interface.

Summing up the requirements on a laser vibrometer standard, the following demands must be met:

- To use a heterodyne or homodyne interferometer with a sufficiently wide bandwidth according to the highest Doppler frequency
- To use a laser with adequate accuracy and stability of wavelength (preferably a HeNe-Laser or any other suitable type with a physically defined wavelength)
- In decoding the vibration signals $s(t)$ or $v(t)$ from the Doppler signal, a digital signal processing method must be used that yields calculable and stable measuring uncertainty as defined in ISO 16063-11
- The laser vibrometer standard should be designed such that it can be traced back to the standard of the relevant metrology institute (PTB in Germany).

- The laser vibrometer standard should have a digital interface to avoid any additional digital-to-analogue and analogue-to-digital signal conversion.

If a laser vibrometer does not meet the requirements mentioned above (for example, if it employs an analogue demodulation method or has only an analogue signal output), it should be treated like a common vibration transducer in the sense of the calibration guide [1]. Such calibration objects will not be considered in this lecture.

MEASURING SETUP

Fig. 3 shows the basic measuring setup in accordance with Fig. 2 of the calibration guide [1]. Fig. 4 shows the same setup in a representation as used in the ISO Standard [2].

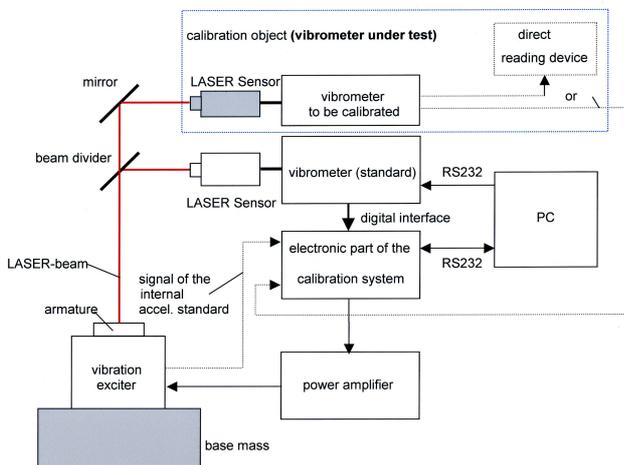


Fig. 3. Block diagram of a primary calibration system for the calibration of laser vibrometer standards (refer to Fig. 2 in [1])

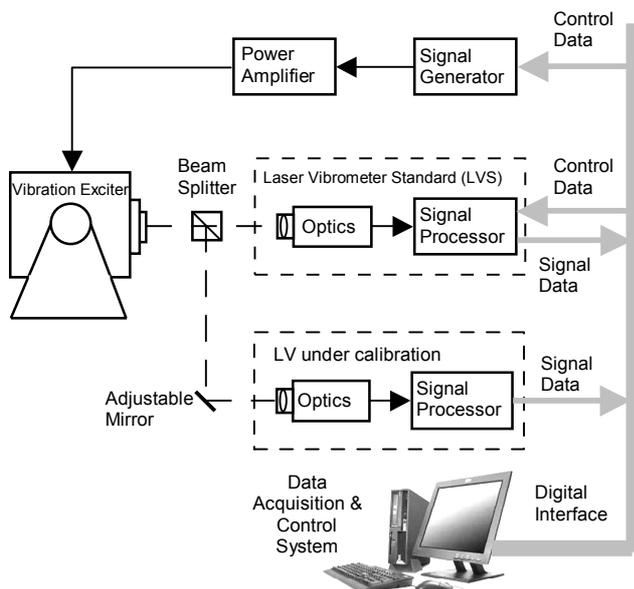


Fig. 4. Block diagram of a primary calibration system for the calibration of laser vibrometer standards (refer to [2])

The paths of both laser beams are represented in a simplified manner. Actually a prism is used that must be designed by the producer of the vibrometer in such a manner that, on one hand, both laser beams are guided to the same tiny spot on the vibrating exciter armature and, on the other, the orthogonal reflection of either laser beam is caused only by the vibrating surface but not by the prism.

Fig. 5 shows the photograph of a primary calibration system for the calibration of laser vibrometer standards according to Fig. 2 in [1]. A photograph of the prism is shown in Fig. 6.

When preparing and performing a calibrating operation, some specific pieces of advice listed and explained in guide [1] should be taken into account. Since this guide is available only in German, some important items are listed below.

- Selection and installation of the vibration exciter: Preferably an airborne exciter with a stiff armature (e.g. beryllium) should be used and mounted on a heavy-weight block of concrete. The central axial insert of the exciter should hold a plane adapter with a polished surface for reflecting the two laser beams.
- Decoupling (neutralizing) exciter and laser optics: Any mutual interaction of the exciter and the laser sensor should be avoided by a dedicated isolating system (see Fig. 2)
- A special prism as shown above should be used for the alignment of the two laser beams.



Fig. 5. Setup of a primary calibration system for the calibration of laser vibrometer standards

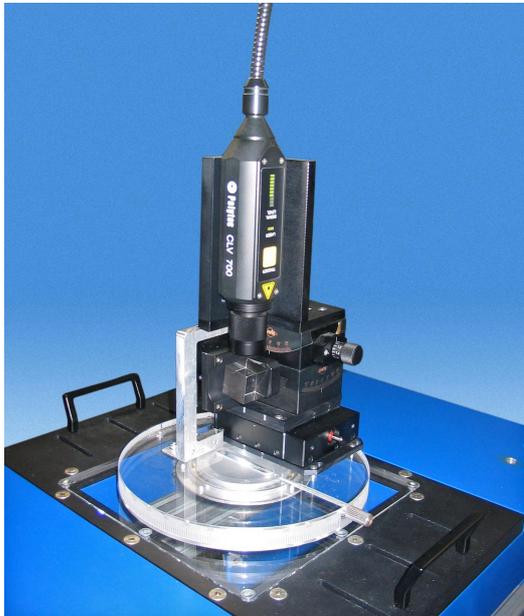


Fig. 6. Photograph of the beam guiding prism

MEASURING RESULTS

Up to now, a number of different laser vibrometer standards have been calibrated by the accredited laboratory of SPEKTRA using the method described above [4]. In addition to that, a system built for the national metrology institute of China (NIM) was calibrated by the SPEKTRA laboratory and the national metrology institute of Germany (PTB at Braunschweig), too. Furthermore the laser vibrometer standard of SPEKTRA was calibrated twice by PTB.

All these operations proved the reliability and accuracy of the described method. In the following section just a few results will be presented.

More results will be presented verbally in the lecture.

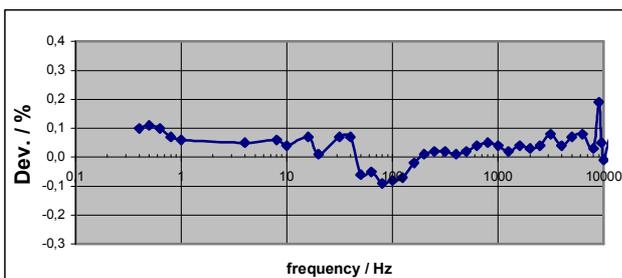


Fig. 7. Diagram from calibration certificate PTB-0819-2004, dated 2004-09-16, Deviation PTB / SPEKTRA
Object: Primary calibration system CS18P, ordered by NIM China, part 1: 0.4 Hz to 10 kHz

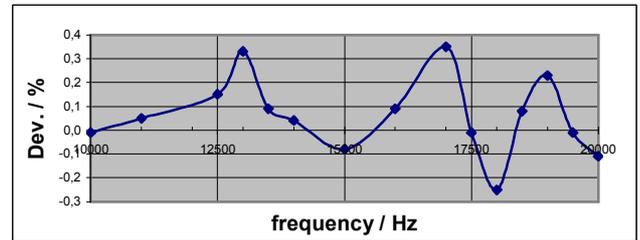


Fig. 8. Diagram from calibration certificate PTB-0819-2004, dated 2004-09-16, Deviation PTB / SPEKTRA
Object: Primary calibration system CS18P, ordered by NIM China, part 2: 10 kHz up to 20 kHz
(For more details see Fig. 7.)

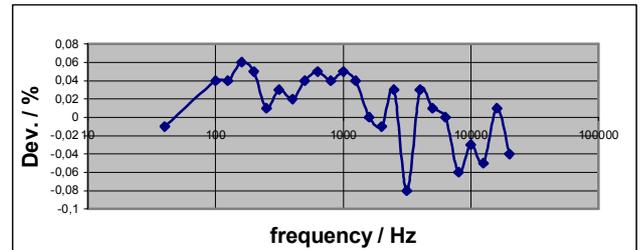


Fig. 9. Diagram of calibration results of the PTB final report, dated 2004-09-24, Deviation PTB / SPEKTRA
Object: Primary calibration system CS18P of the SPEKTRA primary calibration laboratory

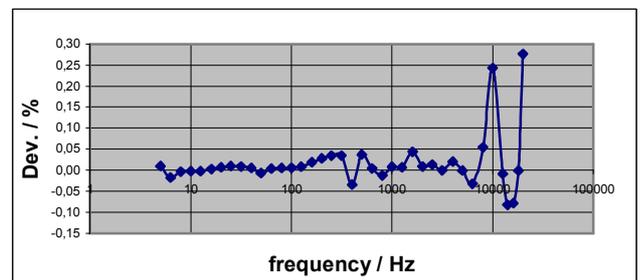


Fig. 10. Diagram of the results of a primary calibration operation, dated 2006-03-27, Deviation PTB / SPEKTRA
Calibration system: CS18P of the SPEKTRA primary calibration laboratory,
Object: Laser vibrometer standard OVF-5000/OVF-505
(For more details see Fig. 11.)

CONCLUSION

SPEKTRA had a major part in initiating and working out the methods for the calibration of reference laser vibrometers as described in [1] and partly those described in [2]. The relevant measurement procedures are implemented in the SPEKTRA primary calibration systems and thus commercially available. The methods and systems described in this paper allow laser vibrometer standards to be calibrated in line with the relevant standards. The measurement results presented in this paper give evidence that the described methods and equipment can be used for tracing back the calibration of laser vibrometer standards with extremely small measurement uncertainty and so fulfill the requirements that must be met when supplying a primary calibration system.

The German directive [1] and the international standard that is currently under preparation [2] constitute the basis for the traceability of calibrations and comparative measurements on laser vibrometers and laser vibrometer standards with results that are commensurable worldwide.

REFERENCES

- [1] DKD-R 3-1 / Blatt 4, "Primaerkalibrierung von Schwingungsmessgeraeten mit sinusfoermiger Anregung und interferometrischer Messung der Schwingungsgroesse"
Deutscher Kalibrierdienst DKD, Braunschweig, Ausgabe Februar 2005, 29 S.
<http://www.dkd.info/de/publikationen.htm>
- [2] ISO 16063-41 / First Working Draft July 2005
"Methods for the calibration of vibration and shock transducers - Part 41: Calibration of Laser Vibrometers"
- [3] U. Buehn, H. Nicklich, "Practical experiences in primary vibration calibration using laser vibrometer technology – measurement uncertainties in wide frequency range applications", AIVELA conference, Ancona Italy, 2004
- [4] U. Buehn, H. Nicklich, "Calibration of laser vibrometer standards according to the standardization project ISO 16063-41", AIVELA conference, Ancona Italy, 2006
- [5] H. Nicklich, U. Buehn, "Primary vibration calibration according to ISO 16063-11 with National Metrology Institute Traceability" msc conference, Anaheim USA, 2006
- [6] M. Bauer, F. Ritter, G. Siegmund, "High-precision laser vibrometers based on digital Doppler-signal processing" AIVELA conference, Ancona Italy, 2002

Results of comparison tests of Laser Vibrometer Standards at SPEKTRA DKD-Laboratory

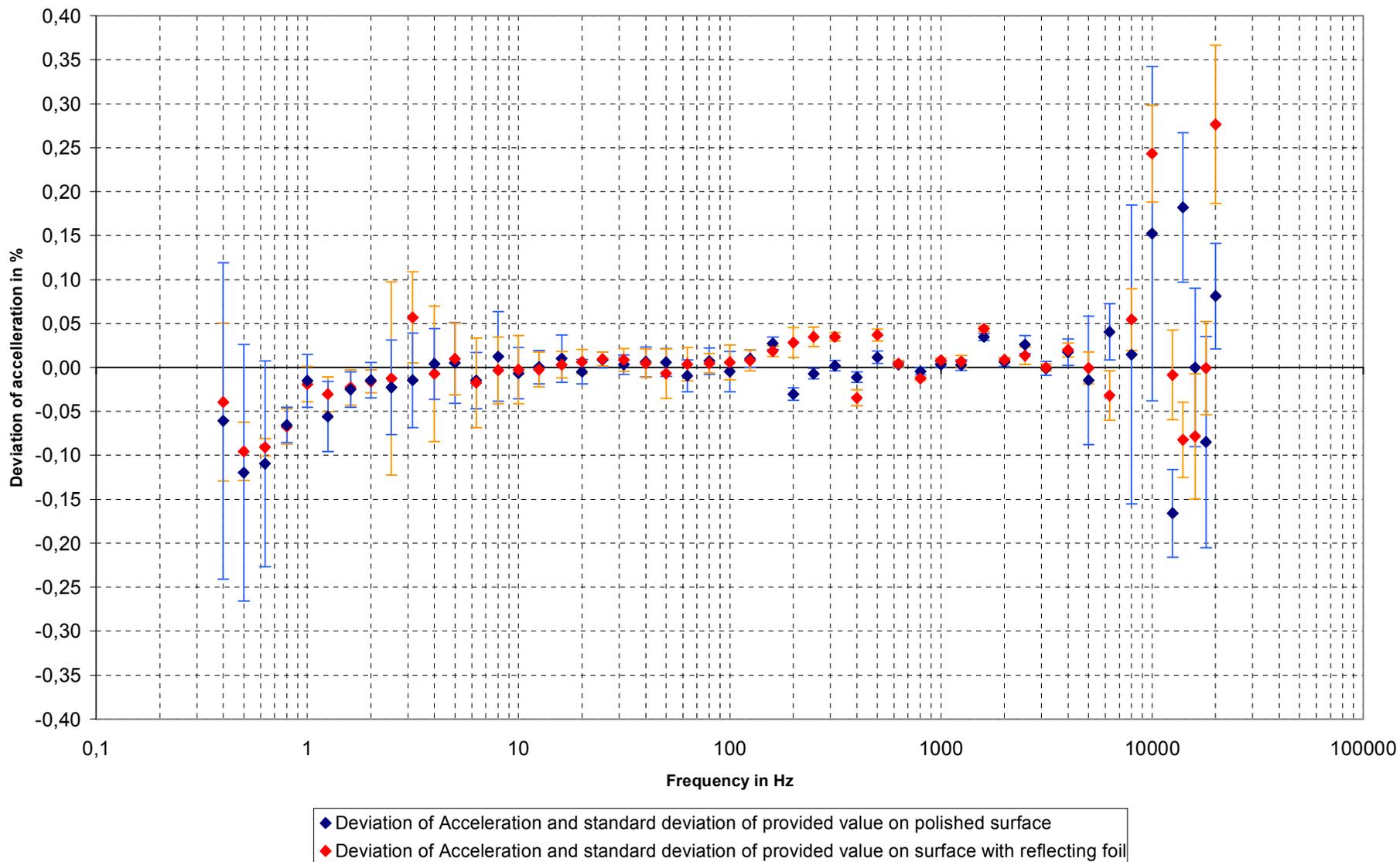


Fig. 11. Diagram of the results of a primary calibration test, dated 2006-03-27, calibration system: CS18P of the SPEKTRA primary calibration laboratory, object: Laser vibrometer OFV-5000/OFV-505 with digital output, useable as laser vibrometer standard