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(cf. Draft Agenda of 28/03/08, item 13.3)

Recent progress of ISO TC 108/SC 3 towards key comparisons and traceability in the field of vibration and shock acceleration

1 Introduction

This report updates the information presented to the 2nd, 3rd , 4th , and 5th meetings of the CCAUV. In the documents CCAUV/99-12, CCAUV/01-05, CCAUV/02-08 and CCAUV/04-06 and CCAUV/06-05 the International Organization for Standardization outlined the regulations for developing and adopting ISO standards, and presented the standards developed in ISO/TC 108/SC 3 (in Working Group WG 6: *Calibration* in particular). With the development of the ISO 16063/XX series of standards, ISO/TC 108 *Mechanical vibration, shock and condition monitoring* responded to the need for upgraded and new standard calibration methods applicable to

- CIPM key comparisons, RMO key comparisons and Supplementary comparisons in the field of vibration and shock measurements
- the reliable and uniform specification of the Calibration and Measurement Capabilities (CMCs) in the branch vibration, published in the BIPM key comparison database (cf. Appendix C of the Mutual Recognition Arrangement MRA) - all NMIs claim their CMCs in the field of vibration and shock acceleration to be in compliance with the relevant ISO standards
- the establishment of traceability chains in the field of vibration and shock (measurands: acceleration, velocity, displacement, angular acceleration, angular velocity and rotational angle).

ISO standards and standardization projects focusing on the specification of calibration methods needed at different levels of a traceability chain in the field of vibration and shock are presented. In the following, the information will be updated outlining the progress achieved since the 5th meeting of the CCAUV. The 28th meeting of ISO/TC 108/SC 3 held in .Berlin/Germany in April 2007 marked a milestone in the ongoing process of developing standards significant for key comparisons and traceability.

2 The standard series ISO 16063 “Methods for the calibration of vibration and shock transducers” (state of August 2008)

Under the general title "Methods for the calibration of vibration and shock pick-ups", a standard series, ISO 5347, was issued in the period between 1987 and 1997. A revision of the ISO 5347 series, re-numbered to ISO 16063, was started in 1995, focusing on the specification of upgraded calibration methods needed at different levels of a traceability chain: methods for primary vibration calibration, secondary

vibration calibration, primary shock calibration and secondary shock calibration. The re-numbering applies to those standards only which are under revision or are being newly developed. Therefore, the former numbering system (i.e. ISO 5347/XX) is still valid for the standards which have recently been reviewed and confirmed without revision. A survey of the state of the standards and standardization projects of the 16063 series is given in the following.

(1) ***ISO 16063-1: Basic concepts***
Issued as international standard in 1998, reviewed and confirmed in 2004

(2) ***ISO 16063-11: Primary vibration calibration by laser interferometry***
Issued as international standard in 1999, reviewed and confirmed in 2004

(3) ***ISO 16063-12: Primary vibration calibration by the reciprocity method***
Issued as international standard in 2002, reviewed and confirmed in 2007 with the decision to develop a technical corrigendum

(4) ***ISO 16063-13: Primary shock calibration by laser interferometry***
Issued as international standard in 2001, reviewed and confirmed in 2006

(5) ***ISO 16063-15: Primary angular vibration calibration by laser interferometry***
Issued as international standard in 2006

(6) ***ISO 16063-21: Vibration calibration by comparison to a reference transducer***
Issued as international standard in 2003

(7) ***ISO 16063-22: Shock calibration by comparison to a reference transducer***
Issued as international standard in 2005

(8) ***ISO 16063-23: Angular vibration calibration by comparison to reference transducers***
Preliminary work item in the programme of work confirmed in 2007

(9) ***ISO 16063-31: Testing of transverse vibration sensitivity***
Revision of ISO 5347-11:1993 approved in 2004, Committee Draft approved in 2007, Draft International Standard in preparation

(10) ***ISO 16063-32: Resonance testing***
Revision of ISO 5347-14:1993 approved in 2004 and confirmed in 2007 as preliminary work item, 3rd preliminary working draft under preparation with extended scope for a combined revision of ISO 5347-14 and ISO 5347-22

(11) ***16063-41: Calibration of laser vibrometers***
New proposed work item approved in 2004, 2nd Committee Draft approved in 2008, Draft International Standard in preparation

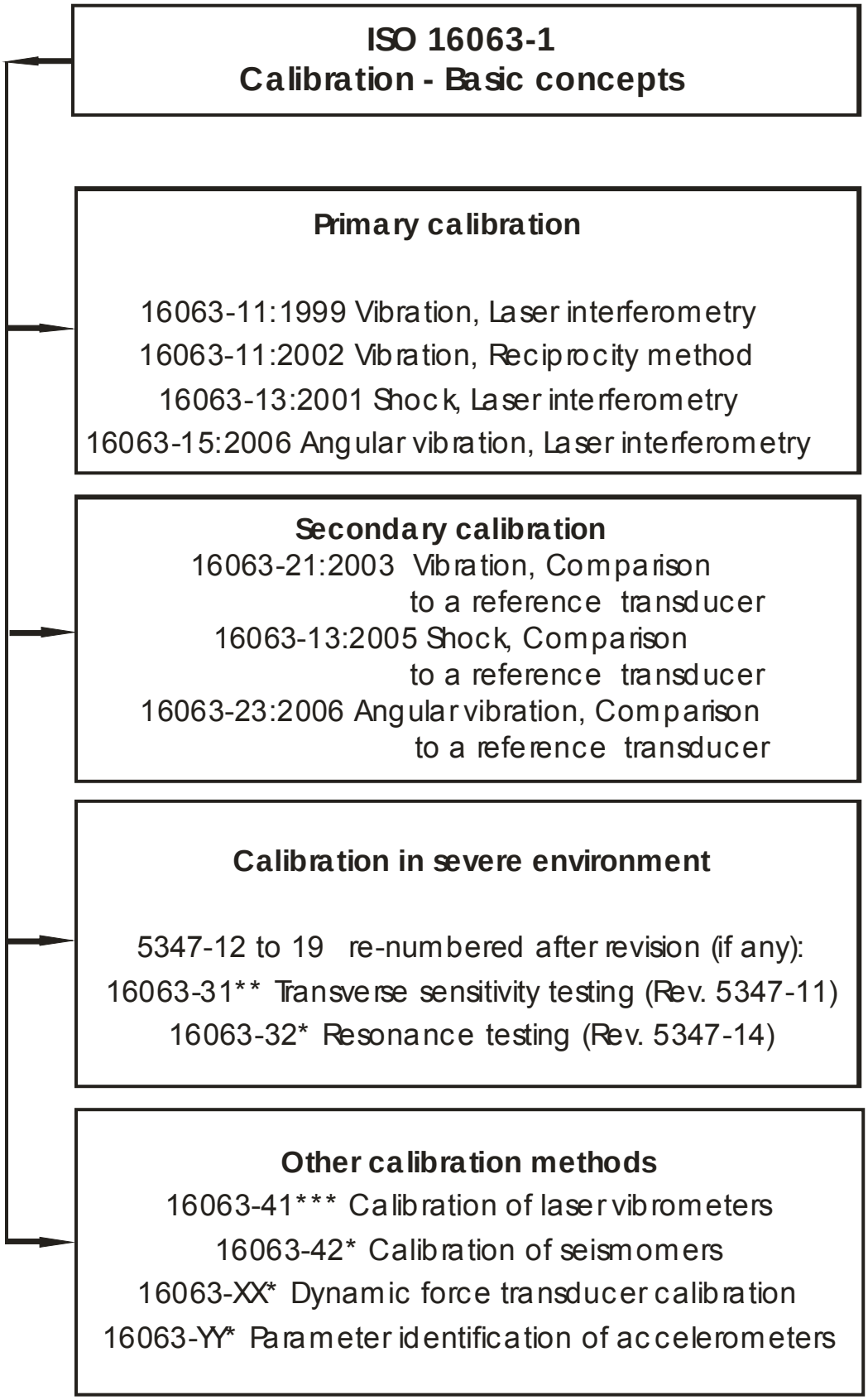
(12) ***ISO 16063-42 Calibration of seismometers***
Preliminary work item in the programme of work, 2004, 2nd preliminary working draft in preparation

(13) ***PWI 21691 Dynamic force transducer calibration***
Preliminary work item approved in 2004, confirmed in 2007 as zero stage project

(14) ***NPWI Parameter identification of accelerometers by primary methods***
New preliminary work item proposed and confirmed in 2007 as zero stage project

Figure 1: State of the standard series ISO 16063 “Methods for the calibration of vibration and shock transducers" (August 2008)

* Zero-stage project, ** Committee Draft , *** 2nd Committee Draft



3 State of the standard series ISO 5347 “Calibration of vibration and shock pick-ups” (August 2008)

Table 1: Survey of standard series ISO 5347

ISO Part	Title	State
5347-0:1987	Basic concepts	revised, 16063-1:1998
5347-1:1993	Primary vibration calibration by laser interferometry	revised, 16063-11:1999
5347-2:1993	Primary shock calibration by light cutting	withdrawn, replaced with 16063-13:2001
5347-3:1993	Secondary vibration calibration	revised, 16063-21:2003
5347-4:1993	Secondary shock calibration	revised, 16063-22:2005
ISO 5347-5:1993	Calibration by Earth's gravitation	confirmed 2004
ISO 5347-6:1993	Primary vibration calibration at low frequencies	withdrawn 2004
ISO 5347-7:1993	Primary calibration by centrifuge	confirmed 2004
ISO 5347-8:1993	Primary calibration by dual centrifuge	confirmed 2004
ISO 5347-9:1993	Secondary vibration calibration by comparison of phase angles	withdrawn
ISO 5347-10:1993	Primary calibration by high impact shocks	confirmed 2004
ISO 5347-11:1993	Testing of transverse vibration sensitivity	confirmed 2004, under revision (16063-31)
ISO 5347-12:1993	Testing of transverse shock sensitivity	confirmed 2004
ISO 5347-13:1993	Testing of base strain sensitivity	confirmed 2004
ISO 5347-14:1993	Resonance frequency testing of undamped accelerometers on a steel block	confirmed 2004, under revision (16063-32)
ISO 5347-15:1993	Testing of acoustic sensitivity	confirmed 2004
ISO 5347-16:1993	Testing of torque sensitivity	confirmed 2004
ISO 5347-17:1993	Testing of fixed temperature sensitivity	confirmed 2004
ISO 5347-18:1993	Testing of transient temperature sensitivity	confirmed 2004
ISO 5347-19:1993	Testing of magnetic field sensitivity	confirmed 2004
ISO 5347-20:1997	Primary vibration calibration by the reciprocity method	revised, 16063-12:2002 confirmed 2007 but technical corrigendum to be developed
ISO 5347-22:1997	Accelerometer resonance testing - General methods	confirmed 2002 and 2007 but to be combined with ISO 5347-14:1993 under revision

4 Recent progress in development and application of ISO calibration standards

4.1 Survey on standards

ISO TC 108/SC 3 “Use and calibration of vibration and shock measuring instruments” (WG 6 “Calibration” in particular) has continued its activities to specify standard methods for the calibration of vibration and shock transducers and measuring instruments required to ensure international traceability to the SI units in the field of measurements of accelerations and derived motion quantities. The progress achieved since the 5th CCAUV meeting is reflected in the Sections 2 and 3 of this report.

Information on the development of the new standard series ISO 16063 will be updated, focusing mainly on the developments since the 5th CCAUV Meeting in September 2006. Progress achieved after September 2006 will be demonstrated only for those projects that have reached an approved Committee Draft stage, considered to proceed to the Draft International Standard stage. No specific information will be given on preliminary projects discussed in working group WG 6 (stage of working drafts, see sections 2 and 3).

The task of ISO TC 108/SC 3/WG 6 is to develop international standards for the calibration of vibration and shock transducers. Various calibration methods have been specified to cover the different levels in the calibration hierarchy, from the highest accuracy level of primary calibration of a reference transducer in a national metrology institute (NMI) down to the lowest accuracy level of a check calibration of an accelerometer under field conditions. Calibration methods for nearly all kinds of vibration and shock transducers and measuring instruments have been specified.

For primary vibration calibration by laser interferometry at NMI level, ISO 16063-11: 1999 had extended the frequency range (0.4 Hz to 10 kHz) and included absolute phase shift measurement.

As an alternative primary methodology to laser interferometry, the reciprocity method for transducer calibration has been specified in ISO 16063-12:2002 (frequency range 40 Hz to 5 kHz). In 2007, this standard was confirmed with the decision to develop a technical corrigendum.

For modulus and phase calibration of rectilinear vibration transducers in the frequency range 0.4 Hz to 10 kHz at lower levels of the traceability chain ISO 16063-21:2003 had specified appropriate methods.

ISO 16063-15:2006 specifies primary angular vibration calibration by laser interferometry (modulus and phase shift) in the frequency range from 0.4 Hz to 1.6 kHz. The corresponding project for angular vibration calibration by comparison to a reference transducer is still on the preliminary stage.

The pair of ISO standards for primary and secondary shock calibration ISO 16063-13:2001 (laser interferometry) and ISO 16063-22:2005 (comparison to a reference transducer) has specified methods and techniques for shock-shaped accelerations of 100 m/s² up to 100 km/s² traceable to primary methodologies but proved to be applicable also at higher shock accelerations (e.g. 1000 km/s²).

The ISO standard project “Testing of transverse vibration sensitivity” (Revision of ISO 5347-11:1993, to become ISO 16063-31, current stage Committee Draft) specifies

different methods using a single-axis vibration generator, a two-axis vibration generator or a triaxial vibration generator. Triaxial vibration excitation allows the transverse sensitivity to be determined with simultaneous excitation of a vibration in the sensitive axis of the transducer, thus simulating application conditions where the transducer is exposed to multi-axial vibration. To measure the motion components in up to three axes, primary methods (laser interferometry) and secondary methods (reference transducer) are specified.

The first international standard for the calibration of laser vibrometers (to become ISO 16063-41), has achieved in 2007 the 2nd Committee Draft stage (approved in 2008). For details, see 4.4.

4.2 Measurement ranges and accuracy specified for standard techniques

For primary calibrations using laser interferometry, the following measurement ranges and expanded uncertainties (k = 2) are specified:

Primary vibration calibration by laser interferometry **(ISO 16063-11):**
It is applicable to a frequency range from 1 Hz to 10 kHz and a dynamic range (amplitude) from 0.1 m/s^2 to 1 000 m/s^2 (frequency-dependent). The limits of the uncertainty of measurement shall be as follows.

For the modulus of sensitivity:

- 0.5 % of the measured value at reference conditions;
- 1 % of the measured value outside reference conditions.

For the phase shift of sensitivity:

- 0.5° of the measured value at reference conditions;
- 1° of the reading outside reference conditions.

Primary shock calibration by laser interferometry **(ISO 16063-13):**

It is applicable in a shock pulse duration range 0.05 ms to 10 ms and a dynamic range (peak value) 10^2 m/s^2 to 10^5 m/s^2 (pulse duration-dependent). The limits of the uncertainty of shock sensitivity measurement shall be as follows:

- 1 % of reading at reference peak value of 1000 m/s^2 and reference shock pulse duration of 2 ms
- $\leq$ 2 % for all values of peak acceleration and shock pulse duration.

Primary angular vibration calibration by laser interferometry **(ISO 16063-15):**

It is applicable to a frequency range from 1 Hz to 1.6 kHz and a dynamic range (amplitude) from 0.1 rad/s^2 to 1 000 rad/s^2 (frequency-dependent). The limits of the uncertainty of measurement shall be as follows:

For the modulus of sensitivity:

- 0.5 % of the measured value at reference conditions; $\leq$ 1 % outside reference conditions.

For the phase shift of sensitivity:

- 0.5° of the measured value at reference conditions; $\leq$1° outside reference conditions.

4.3 Measurement ranges and accuracy (uncertainty) achievable with refined techniques

The International Standards referred to in 4.2 allow special refined versions of the standard methods to be applied, which lead to even higher accuracy and/or wider parameter ranges than that specified for the standard methods. Uncertainty evaluations for measurements using laser interferometry [1] had demonstrated that relative expanded uncertainties (k = 2) < 0.1 % can be attained, e.g., 0.028 % in a measurement of a displacement amplitude 2 µm, and 0.065 % in a measurement of an accelerometer sensitivity (modulus) of 0.123 pC/(m/s²) at a vibration frequency of 800 Hz using the fringe-counting method. Experimental investigations reported in [2] and [3] verified such high accuracy (expanded uncertainties < 0.1 %) attainable in vibration measurements and calibrations. In simultaneous vibration measurements using different methods and techniques, no bias (systematic deviation) could be found between the different ISO standard methods using laser interferometry (Methods 1, 2 and 3). This is valid within an uncertainty in the order of 0.01 % of the analysis of experimental results shown in Table 6 of Ref. [3]. Specific recommendations to suppress disturbing effects are given in [3] and [5].

4.4 Extension of vibration frequency range to 100 kHz and higher

Experimental investigations and comparisons of specific calibration methods specified in parts 11 and 21 of ISO 16063 have demonstrated that they are capable for higher frequencies [2] [3] [4] [6]. This has been taken into account by their adaptation and specification for calibrations of laser vibrometers up to the order of 100 kHz (see Tables 2 and 3).

A draft of an international standard under development is not available to the public. Because of the importance of ISO 16063-41, the project leader of this standardization project (author of this report) gives some significant information.

ISO 16063-41 specifies the instrumentation and procedures for performing primary and secondary calibrations of rectilinear laser vibrometers in the frequency range between 0.4 Hz and 50 kHz and higher. It describes the calibration of laser vibrometer standards designated for the calibration of either laser vibrometers or mechanical vibration transducers, as well as the calibration of laser vibrometers by a laser vibrometer standard or by comparison to a reference transducer calibrated by laser interferometry.

Table 2: Comparison of ISO 16063-11 (Calibration of accelerometers) and ISO 16063-41 (Calibration of laser vibrometers) demonstrating the need for a new ISO standard for the calibration of laser vibrometers

Property	ISO 16063-11	ISO 16063-41
Frequency range	0.4 Hz to 10 kHz	0.4 Hz to 50 kHz (provisions for higher frequencies)
Vibration generator	Electrodynamic	• Electrodynamic • Piezoelectric (→high frequency)
Measurement method	Interferometry	• Interferometry • Comparison
Interferometer technique	Homodyne	• Homodyne • Heterodyne (→high frequency)
Terms and test methods	Specified in some detail	Defined in a separated clause, specified in great detail
Applicability of commercial laser vibrometer standards	Not included	Detailed specification
Calculation of measurement uncertainty	Uncertainty components in calibration	• Uncertainty components in calibration • Example of uncertainty calculation

Table 3 : Applicability of calibration methods of ISO 16063-41 influencing the uncertainty of measurement

Marking of method	Characterization of method (optical transducer/signal treatment)
Method 1	Homodyne interferometer (single output signal/ fringe counting)
Method 2	Homodyne interferometer (single output signal/ spectral analysis)
Method 3 (homodyne)	Homodyne interferometer (two output signals in quadrature / sine approximation)
Method 3 (heterodyne)	Heterodyne interferometer (output with frequency offset / sine approximation)
Method 4	Comparison to a reference transducer calibrated by Method 1, 2 or 3 in the arrangement used for laser vibrometer calibration

For each interferometric method specified in ISO 16063-41 (see Table 3), currently a specific frequency range applies. In fact, the applicability of the particular methods mainly depends on the displacement or velocity amplitudes measurable within given measurement uncertainties. These, however, not only depend on the measurement method itself but also on the frequency-dependent properties of the vibration exciters available. Using adequate vibration exciters to generate sufficient displacement or velocity amplitudes, the upper frequency limits of all methods can be expanded to 100 kHz and even beyond.

5 Summary and conclusions

ISO TC 108 was established in 1964 to develop documentary standards for mechanical vibration and shock, including transducer calibration. The calibration standards 5347 series and the 16063 series comprise over 20 standards. The ISO

TC 108/SC 3 includes recognized metrologists (a number of whom are CCAUV members) from national metrology institutes along with a wide range of manufacturers and users. The ISO 5347 and 16063 series are under continuous development to provide a documentary standard base needed to ensure world-wide uniformity of vibration and shock measurements and calibrations and their traceability to the international system of units (SI). In particular, ISO standards have specified various methods and techniques for vibration and shock measurements and calibrations, applicable to perform international comparisons of national measurement standards organized under the auspices of the BIPM (CCAUV).

The realization and dissemination of the SI units of motion quantities (vibration and shock) have been based on laser interferometer methods specified in international documentary standards. New and upgraded ISO standards were reviewed with respect to their suitability for ensuring traceable vibration measurements and calibrations in an extended frequency range of 0.4 Hz to higher than 100 kHz. Using adequate vibration exciters to generate sufficient displacement or velocity amplitudes, the upper frequency limits of the laser interferometer methods specified in ISO 16063-11 for frequencies ≤ 10 kHz can be expanded to 100 kHz and beyond, as demonstrated in Fig. 2.

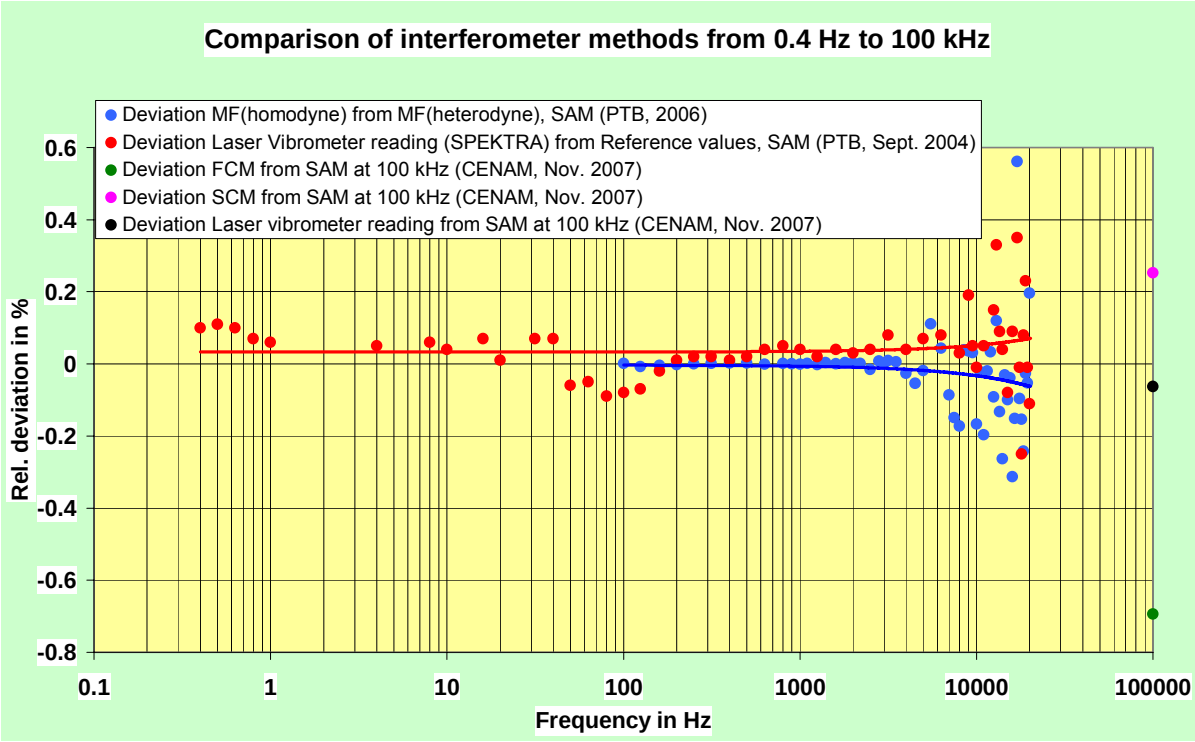


Figure 2: Deviations between measurement results of different interferometer methods in the frequency range from 0.4 Hz to 100 kHz
FCM Fringe-counting method, SAM Sine-approximation method, SCM Signal coincidence method [6]

Using the ISO methods specified, hierarchies of measurement standards (traceability chains) have been established and are operated by national metrology institutes (NMIs) as well as accredited and non-accredited calibration laboratories in compliance with the upgraded and new ISO standards [3] [5].

For key comparisons at the CIPM and RMO levels and supplementary comparisons in the field of vibration and shock measurements (quantity of acceleration), the methods specified in the relevant ISO standards are used - preferably primary vibration calibration by laser interferometry as specified in ISO 16063-11 and

secondary calibration by comparison to a reference transducer as specified in ISO 16063-21 (e.g. [7] [8] [9] [10]). Both standards are limited to the maximum frequency of 10 kHz. The new standard ISO 16063-41 for the calibration of laser vibrometers (2nd Committee Draft approved, Draft International Standard DIS in preparation) will extend the frequency range of the primary calibration standard methods and techniques to 100 kHz and higher [4]. This includes the calibration of laser vibrometer standards commercially available and used in numerous NMIs and increasingly also in accredited calibration laboratories for primary calibrations of accelerometers or optical transducers (laser vibrometers as ordinary measuring instruments included).

The calibration and measurement capabilities (CMCs) offered in Appendix C of the Mutual Recognition Arrangement MRA (see. http://www.bipm.org, Key Comparison Database) for the branch vibration are based on the up-to-date ISO standard methods.

References

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