CCAUV/12-02

Hans-Jürgen von Martens
Permanent Representative of ISO TC 108 to BIPM/ CCAUV

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(cf. Draft Agenda of 13/06/2012, item 16.3)

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 to 7th meetings of the CCAUV. In the documents CCAUV/99-12, CCAUV/01-05, CCAUV/02-08, CCAUV/04-06, CCAUV/06-05, CCAUV/08/01 and CCAUV/10-03, 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 7th meeting of the CCAUV. The 30th meeting of ISO/TC 108/SC 3 held in London/ UK in September 2010 has marked further milestones in the ongoing process of developing standards significant for key comparisons and traceability.

NOTE: This CCAUV working document submitted to the BIPM for inclusion in the collection of CCAUV working documents of the 8th CCAUV Meeting (BIPM website for restricted access) indicates the state of 30th April of the ISO standardization projects under development, revision and review, respectively. The upcoming 31th ISO TC 108/SC 3 Meeting (25th to 29th June 2012) will achieve further progress to be reported at the 9th meeting of the CCAUV.

2 The standard series ISO 16063 “Methods for the calibration of vibration and shock transducers”

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 (see also references [1] to [9]).

ISO 16063-1 Basic concepts
Issued as international standard in 1998, reviewed and confirmed in 2004 and 2009

ISO 16063-11 Primary vibration calibration by laser interferometry
Issued as international standard in 1999, reviewed and confirmed in 2004 and 2009

ISO 16063-12 Primary vibration calibration by the reciprocity method
Issued as international standard in 2002, reviewed and confirmed in 2007 with a Technical Corrigendum issued in 2008 (Cor.1:2008), up for review in 2012 with a deadline of 2012-06-15

ISO 16063-13 Primary shock calibration by laser interferometry
Issued as international standard in 2001, reviewed and confirmed in 2006 and 2012.

ISO 16063-15 Primary angular vibration calibration by laser interferometry
Issued as international standard in 2006, reviewed and confirmed in 2009

ISO 16063-16 Calibration by Earth’s gravity
Revision of ISO 5347-5:1993, 1st CD in 2011

ISO 16063-21 Vibration calibration by comparison to a reference transducer
Issued as international standard in 2003, reviewed and confirmed in 2008 with a Technical Corrigendum issued in 2009 (Cor.1:2009)

ISO 16063-22 Shock calibration by comparison to a reference transducer
Issued as international standard in 2005, reviewed and confirmed in 2008

ISO 16063-23 Angular vibration calibration by comparison to reference transducers
Preliminary work item in the programme of work confirmed in 2010

ISO 16063-31 Testing of transverse vibration sensitivity
Issued as international standard in 2009

ISO 16063-32 Resonance testing
Revision of ISO 5347-14:1993, 1st CD in 2011

ISO 16063-33 Testing of magnetic field sensitivity
Revision of ISO 5347-1993, 1st CD 2011

ISO 16063-41: Calibration of laser vibrometers
Issued as international standard in 2011

ISO 16063-42 Calibration of seismometers
Preliminary work item in the programme of work, 1st CD in 2011

ISO 16063-43 Calibration of accelerometers by model based parameter identification
Preliminary work item in the programme of work, confirmed in 2010, 1st WD in 2008

ISO 16063-4X Calibration of hand held accelerometer calibrators
New preliminary work item in the programme of work, confirmed in 2010

ISO 16063-4Y (PWI 2169) Dynamic force transducer calibration
Preliminary work item in the programme of work, confirmed in 2010

16063-1:1998: Calibration – Basic concepts

Primary Calibration

16063-11:1999:	Vibration, Laser interferometry
16063-12:2002:	Vibration, Reciprocity method
16063-13:2001:	Shock, Laser interferometry
16063-15:2006:	Angular vibration, Laser interferometry
16063-16**:	Earth's gravitation (Revis. 5347-5)

Secondary Calibration

16063-21:2003:	Vibration, Comparison to a reference transducer
16063-22:2005:	Shock, Comparison to a reference transducer
16063-23*:	Shock, Comparison to a reference transducer

Calibration in severe environment

5347-12 to 19 renumbered after revision (if any)

16063-31:2009:	Transverse sensitivity testing (Revis. 5347-11)
16063-32**:	Resonance testing (Revis. 5347-14)
16063-33**:	Testing of magnetic sensitivity

Other calibration methods

16063-41:2011:	Calibration of laser vibrometers
16063-42**:	Calibration of seismometers
16063-43*:	Parameter identification of accelerometers
16063-4X*:	Calibration of hand held accelerometer calibrators
16063-4Y*:	Dynamic force transducer calibration

Figure 1: State of the standard series ISO 16063 "Methods for the calibration of vibration and shock transducers" (April 2012)

* Preliminary work item (zero-stage project), ** Committee Draft (CD)

3 State of the series ISO 5347 “Calibration of vibration and shock pick-ups”

Table 1 Survey of standard series ISO 5347

ISO Part	Title	State
5347-0:1987	Basic concepts	revised → 16063-1:1998, the latter confirmed 2009
5347-1:1993	Primary vibration calibration by laser interferometry	revised → 16063-11:1999, the latter confirmed 2009
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, with tech. corrigendum Cor.1:2009
5347-4:1993	Secondary shock calibration	revised → 16063-22:2005, the latter confirmed 2008
ISO 5347-5:1993	Calibration by Earth's gravitation	under revision → 16063-61
ISO 5347-6:1993	Primary vibration calibration at low frequencies	withdrawn
ISO 5347-7:1993	Primary calibration by centrifuge	confirmed 2010
ISO 5347-8:1993	Primary calibration by dual centrifuge	confirmed 2010
ISO 5347-9:1993	Secondary vibration calibration by comparison of phase angles	withdrawn
ISO 5347-10:1993	Primary calibration by high impact shocks	withdrawn
ISO 5347-11:1993	Testing of transverse vibration sensitivity	revised → 16063-31:2009
ISO 5347-12:1993	Testing of transverse shock sensitivity	confirmed 2009
ISO 5347-13:1993	Testing of base strain sensitivity	confirmed 2009
ISO 5347-14:1993	Resonance frequency testing of undamped accelerometers on a steel block	under revision → 16063-32
ISO 5347-15:1993	Testing of acoustic sensitivity	confirmed 2009
ISO 5347-16:1993	Testing of torque sensitivity	confirmed 2009
ISO 5347-17:1993	Testing of fixed temperature sensitivity	confirmed 2009
ISO 5347-18:1993	Testing of transient temperature sensitivity	confirmed 2009
ISO 5347-19:1993	Testing of magnetic field sensitivity	confirmed 2009
ISO 5347-20:1997	Primary vibration calibration by the reciprocity method	revised → 16063-12:2002, with tech. corrigendum Cor.1:2008; up for review in 2012
ISO 5347-22:1997	Acc. resonance testing - General methods	confirmed 2009

4 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 of vibration and shock transducers” 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 7th CCAUV meeting is reflected in the Sections 2 and 3 of this report.

In this report, information on the development of the new standard series ISO 16063 is updated, focusing mainly on the developments since the 7th CCAUV Meeting (BIPM; October 2010). No specific information will be given on preliminary work items (PWIs) indicated in 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.

The ISO standard 16063-1:1998, Methods for the calibration of vibration and shock transducers – Part 1: Basic concepts, reviewed and confirmed in 2004 and 2009, is frequently used, particularly the adaptation of the GUM [10] to evaluate the uncertainty of measurement in calibrations of vibration and shock transducers (Annex A of the standard).For primary vibration calibration by laser interferometry at NMI level, ISO 16063-11: 1999, reviewed and confirmed in 2004 and 2009, 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 which was published in 2008 (Cor. 1:2008).

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 based on comparison with a reference transducer. This ISO standard was confirmed 2008 with the decision to develop a technical corrigendum which was published in 2009 (Cor. 1:2009).

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).

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. This ISO standard was reviewed and confirmed in 2009. The corresponding project for angular vibration calibration by comparison to a reference transducer (to become ISO 16063-23) is still on the preliminary stage (PWI).

The ISO standard project “Testing of transverse vibration sensitivity” (Revision of ISO 5347-11:1993) was completed with the publication of ISO 16063-31:2009. This international standard 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 development of the first international standard for the calibration of laser vibrometers was accomplished with the publication ISO 16063-41:2011. The progress achieved is briefly described in sections 4.4 and 4.5.

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;
- ≤ 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;
- ≤ 1 % outside reference conditions.

For the phase shift of sensitivity:

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

4.3 Accuracy (uncertainty of measurement) 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 (smaller uncertainty of measurement) and/or wider parameter ranges than that specified for the standard methods.

Uncertainty evaluations (e.g. [11], [12]) and experimental investigations (e.g. [12], [13]) of measurements and calibrations using laser interferometry had demonstrated that relative expanded uncertainties (k = 2) < 0.1 % can be attained in calibrations of accelerometer standards at frequencies between 0.4 Hz and 5 kHz and of laser vibrometer standards between 0.4 Hz up to 20 kHz (measurand magnitude of sensitivity).

In simultaneous vibration measurements using different methods and techniques, no significant systematic deviation (bias) of the ISO laser interferometer methods (Method 1: Fringe-counting method, Method 2: Minimum-point method, Method 3: Sine-approximation method) from the SI unit could be found. This is valid within an uncertainty in the order of 0.01 % of the analysis of experimental results shown in Table 6 of Ref. [12].

Specific recommendations to suppress disturbing effects are given in [12] ,[15], [17].

4.4 Extended measurement ranges of standard methods

The ISO standards 16063-11 and 16063-15 specify for the interferometric measurement methods 1, 2 and 3 a specific frequency range, e.g. ISO 16063-11 the range from 1 Hz to 800 Hz for Method 1, 800 Hz to 10 kHz for Method 2 and 1 Hz to 10 kHz for Method 3. 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 three measurement methods can be expanded to higher than 100 kHz (see Fig. 2). Such wide measurement ranges are, however, applicable only to the calibration of laser vibrometers (ISO 16063-41) and not to the calibration of accelerometers (ISO 16063-11). For accelerometer calibrations in accordance with to ISO 16063-11:1999, the advanced state of techniques allowed the specified upper frequency of 10 kHz to be increased to 20 kHz. This is the upper frequency limit offered by NIST and by PTB in their CMCs (see Appendix C of the MRA, http://www.bipm.org, Key Comparison Database). Moreover, a calibration laboratory in Germany (DKD-KL 27801) has been accredited for the calibration of accelerometers and laser vibrometers in the extended frequency range 0.2 Hz to 20 kHz. In the respective calibration certificates, compliance with ISO 16063-11:1999 may be stated, but a mark such as “extended to 20 kHz” should be made to indicate that the frequency limit stated in the ISO standard is exceeded. The alternative way to revise ISO 16063-11:1999 (to change the scope to the extended range up to 20 kHz) was discussed within the framework of the periodic reviews of the ISO standard (2004 and 2009). It was decided to confirm the standard in view of the acceptability of the other specifications and of the time-consuming ISO procedures for a revision of an international standard.

A similar situation may be encountered with ISO 16063-21:2003 (vibration calibration by comparison to a reference transducer) which specifies the frequency range from 0.4 Hz to 10 kHz. It turned that the method and procedures specified in that ISO standard are also applicable to lower and higher frequencies (e.g. 0.2 Hz and 20 kHz, respectively) if appropriate up-to-date techniques are used. In the respective calibration certificates, compliance with ISO 16063-21:2003 may be stated, but a mark such as “extended to 0.2 Hz” or “extended to 20 kHz” should be made. For the measurement of shock-shaped accelerations this is valid in a modified way: ISO 16063-13 specifies the instrumentation and procedure to be used for primary shock calibration of rectilinear accelerometers, using laser interferometry to sense the time-dependent displacement during the shock event. The scope of this ISO standard specifies that the method is applicable in a shock pulse duration range 0.05 ms to 10 ms and a dynamic range (acceleration peak value) 10^2 m/s² to 10^5 m/s² (pulse duration-dependent). However, peak values higher than 100 km/s² can be measured in conjunction with an appropriate high-acceleration shock exciter if the maximum velocity is measurable by the interferometer system. Thus, a standard method and procedure specified in ISO 16063-13 for shock calibrations up to 100 km/s² may be applied to higher acceleration peak values provided that the uncertainty requirements specified in this ISO standard are complied with. This is one of the reasons why ISO 16063-13:2001 was confirmed in 2006 and in 2012, too.

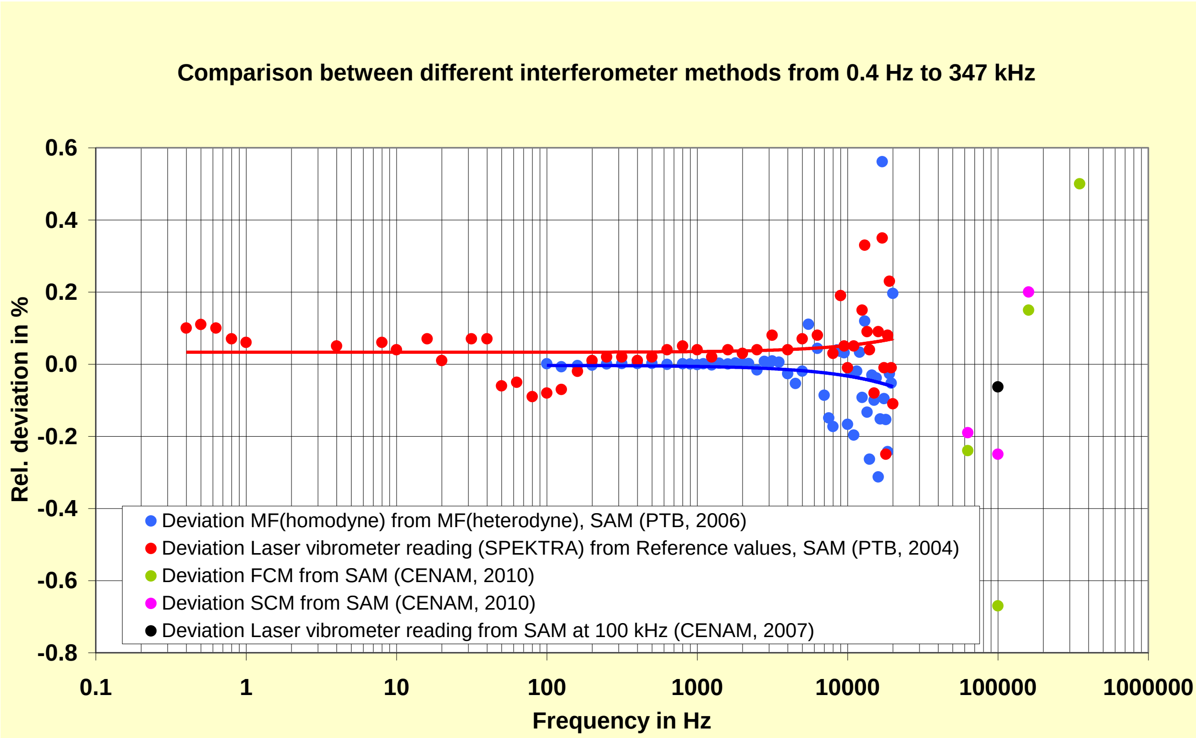

Figure 2 : Deviations between measurement results of different interferometer methods in the frequency range from 0.4 Hz to 347 kHz. Measurement results taken from [12] to [16]. FCM Fringe-counting method, SAM Sine-approximation method, SCM Signal coincidence method.

Figure 2 includes, in addition to results in the usual frequency range 0,4 Hz to 20 kHz, results obtained at the resonance frequencies 63.8 kHz, 100 kHz, 159.4 kHz and 347 kHz of specific piezoelectric vibration actuators used for this purpose [20]. Table 2 demonstrates applicability of ISO Standard Methods at such high frequencies.

Table 2 Demonstration of applicability of ISO Standard Methods at high frequencies. Data taken from [16], analyzed in [23].

2a. Survey of results of FCM, SAM and SCM at all frequencies used in the experiments

Frequency/ Mean value	62,8 kHz	100 kHz	159,4 kHz	347 kHz
FCM	158,13 nm	157,53 nm	158,01 nm	79,06 nm
SAM	158,51 nm	158,60 nm	157,90 nm	78,66 nm
SCM	158,21 nm	158,21 nm	158,21 nm	79,1 nm

2b. Standard deviation within series of repeat measurements (200 single values at 100 kHz, 25 single values at the other frequencies)

Frequency/ Rel. st. deviation	62,8 kHz	100 kHz	159,4 kHz	347 kHz
FCM	0,14 % - 0,23 %	0,20 %	0,05 % - 0,22 %	0,18 % - 0,49 %
SAM	0,11 % - 0,23 %	0,20 %	0,04 % - 0,37 %	0,48 % - 0,52 %

2c. Standard deviation of a total of the single values at a frequency (over 3 series at 62,8 kHz, 3 series at 159,4 kHz, 5 series at 347 kHz)

Frequency/ Rel. st. deviation	62,8 kHz	100 kHz	159,4 kHz	347 kHz
FCM	0,18 %	-	0,16 %	0,60 %
SAM	0,19 %	-	0,24 %	0,92 %

2d. Deviations between the mean measurement results of the different methods used simultaneously

Frequency/ Rel. deviation	62,8 kHz	100 kHz	159,4 kHz	347 kHz
FCM - SAM	-0,24 %	-0,67 %	0,15 %	0,50 %
SCM - SAM	-0,19 %	-0,25 %	0,20 %	0,56 %
FCM - SCM	-0,05 %	-0,42 %	-0,13 %	-0,05 %

As a metrological foundation of the first international standard for the calibration of laser vibrometers, experimental investigations were performed which proved that the standard methods specified for fringe counting (Method 1), minimum point detection (Method 2) and sine approximation (Method 3), as well as the Signal coincidence method (explained in ISO DIS 16063-41, sub-clause 3.2.1, NOTE 3) allow displacement amplitudes, velocity amplitudes and acceleration amplitudes of sinusoidal vibrations to be measured at frequencies up to about 350 kHz with a relative measurement uncertainty (coverage factor 2) of ≤ 1 %. The conclusions and recommendation for the specification of the apparatus, methods and procedures in the standard 16063-41 under development were presented in time to ISO TC 108/ SC 3/WG 6 as background information (e.g. [21]).

During the development of this standard, an appropriate approach was applied to take any potential progress in calibration techniques and procedures into account: In the scope, the wording

“*This part of ISO 16063 specifies the instrumentation and procedures for performing primary and secondary calibrations of rectilinear laser vibrometers in the frequency range* <u>*typically*</u> *between 0,4 Hz and 50 kHz”*

has offered provisions for lower and higher frequencies. Metrological investigations such as reported in [14] [15] [16] [21] [23] demonstrate the typical approach applied in any standardization project for the calibration of vibration and shock transducers (including laser optical transducers and laser vibrometers): The ISO standards are to be based on up-to-date metrology.

4.5 The new standard ISO 16063-41:2011 “Calibration of laser vibrometers”

ISO 16063-41 specifies the instrumentation and procedures for performing primary and secondary calibrations of rectilinear laser vibrometers in the frequency range typically between 0.4 Hz and 50 kHz. 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.

Tables 2 and 3 demonstrate an even more inclusive approach applied to ISO 16063-41, compared with ISO 16063-11, to provide a variety of applicable techniques and procedures. A specific problem of the new ISO standard 16063-41:2011 is that laser vibrometers are available for vibration frequencies up to the MHz and even GHz regions. To date, vibration exciters for such high frequencies have not been provided. To give a recommendation on how traceability to the SI unit may be established also for such high frequencies (MHz range), a NOTE in 16063-41 states the following:

“Calibration of such laser vibrometers can be limited to calibration of their signal processing sub-systems utilising appropriate synthetic Doppler signals under the following preconditions:

- *Synthetic Doppler signals as an equivalent substitute for the output of the photodetector can be generated with defined accuracy requirements.*
- *The optical subsystem of the laser vibrometer to be calibrated has been proven to comply with defined accuracy requirements.”*

More detailed specifications of this approach are not subject of ISO 16063-41 but reference is given to a paper from the NMI of Japan (NMIJ) which describes a method, technique and procedure for demodulator calibration using an RF signal generator and shows experimental results [18]. The paper [22] discusses in detail problems of the calibration and possible solutions of the determination of the metrological properties of laser vibrometers at high frequencies up to the GHz range.

Table 3 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, and a more inclusive approach

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 4 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

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 (NMIs) 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 higher than 100 kHz, as demonstrated in Fig.2.

Using the ISO methods specified, hierarchies of measurement standards (traceability chains) have been established and are operated by NMIs and calibration laboratories in compliance with the upgraded and new ISO standards.

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. Both standards specify a maximum frequency of 10 kHz but proved to be applicable at least up to 20 kHz, using advanced techniques. The new standard ISO 16063-41 for the calibration of laser vibrometers has extended the frequency range of the primary calibration standard methods and techniques to higher than 100 kHz. This includes the calibration of laser vibrometer standards commercially available and used in numerous NMIs as well as 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.

For uncertainty evaluations of measurements to be performed in accordance with the GUM [10], within the framework of key comparisons, of CMC specifications and of calibrations for accredited calibration laboratories and other clients, the ISO standards of the series 16063 have provided an adaptation of the GUM to the calibration of vibration and shock transducers as stated in ISO standard for basic concepts, ISO 16063-1:1998, Annex A [1], and lists of the main principal components of the uncertainty budgets for the specific calibration methods and procedures specified in the respective ISO standards (e.g. ISO 16063-11, Annex A [2], ISO 16063-21, Annexes A and D [6], ISO 16063-41, Annexes A and C [9]). The ISO standards [6] and [9] demonstrate concrete examples of the evaluation of the measurement uncertainty in calibrations of an accelerometer and a laser vibrometer, respectively.

Acknowledgment

The specifications of the new ISO Standard [9] regarding the applicability of the interferometric vibration measurement standard methods up to high frequencies are based on specific metrological investigations performed in 2007 and 2010 at the NMI of Mexico - Centro Nacional de Metrologia (CENAM) - with the collaboration of the author of this report. Hans-Jürgen von Martens is grateful to the General Director of CENAM, Dr. Hector Nava, to the Director of the Area of Physics Metrology, Dr. Salvador Echeverria Villagómez, and to the Head of Division of Vibrations and Acoustics, Dr. Guillermo Silva Pineda, for providing the support of his visits to CENAM. He thanks particularly Dr. Guillermo Silva Pineda and his scientific and technical staff of CENAM's Vibration Laboratories for their skills, expertise and commitment in preparation and accomplishment of the collective experiments.

H.-J. von Martens who sent his apologies thanks Mr. Ian Veldman (South Africa) for representing the ISO at the 8th CCAUV Meeting as substitute to the ISO/TC 108 permanent representative, authorized by the ISO Secretary-General, including the presentation of this report according to the Draft Agenda of 13/06/2012, item 16.3.

H.-J. von Martens asked the Technical Committee ISO TC 108, on the occasion of its forthcoming TC Meeting, to formally approve his actions as the ISO/TC 108 permanent representative to the BIPM/ CCAUV, and recommends to nominate Mr. Ian Veldman as the future permanent representative.

References

[1] International Standard ISO 16063-1, Methods for the calibration of vibration and shock transducers – Part 1: Basic concepts, *Int. Org. for Standardization* (*ISO*), Geneva (1998)

[2] International Standard ISO 16063-11, Methods for the calibration of vibration and shock transducers – Part 11: Primary vibration calibration by laser interferometry, *Int. Org. for Standardization* (*ISO*), Geneva (1999)

[3] International Standard ISO 16063-12, Methods for the calibration of vibration and shock transducers – Part 12: Primary vibration calibration by the reciprocity method, *Int. Org. for Standardization* (*ISO*), Geneva (2002)

[4] International Standard ISO 16063-13, Methods for the calibration of vibration and shock transducers – Part 13: Primary shock calibration using laser interferometry, *Int. Org. for Standardization* (*ISO*), Geneva (2001)

[5] International Standard ISO 16063-15, Methods for the calibration of vibration and shock transducers – Part 15 Primary angular vibration calibration by laser interferometry, *Int. Org. for Standardization* (*ISO*), Geneva (2006)

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