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ISO 16063; A COMPREHENSIVE SET OF VIBRATION AND SHOCK CALIBRATION STANDARDS

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Abstract: The International Organization for Standardization (ISO) has developed a set of standards for the calibration of vibration and shock transducers. These standards cover the various aspects of the calibration of vibration and shock transducers and at different accuracy levels. This paper presents the author's overview of the standards. He investigates and reports on the implementation and application of these standards in an accredited laboratory setup.

Keywords: ISO 16063, vibration transducer, calibration standard.

1. INTRODUCTION

It would soon be noticeable if there were no standards.. Standards have an enormous impact on most aspects of our lives - although very often, that impact is not directly visible.

In 1946, delegates from 25 countries met in London and decided to create a new international organization, with the objective of "facilitating the international coordination and unification of industrial standards". The new organization, the International Organization for Standardization (ISO), officially began operations on 23 February 1947.

ISO is a global network that identifies what International Standards are required by business, government and society, develops them in partnership with the sectors that will put them to use, adopts them by transparent procedures based on national input and delivers them for implementation worldwide.

ISO standards avoid having to reinvent the wheel. They distil the latest in expert knowledge and make it available to all. In this way, they propagate new advances and transfer technology, making them an invaluable source of knowledge.

ISO standards are voluntary. As a non-governmental organization, ISO has no legal authority to enforce the implementation of their standards. A certain percentage of ISO standards however have been adopted in some countries as part of their regulatory framework, or are referred to in legislation, for which they serves as the technical basis. Such adoptions are sovereign decisions by the regulatory authorities or governments of the countries concerned.

1.1. Working Group 6 of TC108/SC3

Within ISO, Technical Committee 108 (TC108) covers standardization in the field of mechanical vibration and shock and condition monitoring and diagnostics. The scope of subcommittee 3 (SC3) of TC108, covers the use and calibration of vibration and shock measuring instruments. Working group 6 (WG6), responsible for standards relating to the calibration of vibration and shock transducers, reside within SC3.

In the late 1990's TC108/SC3/WG6 began to review the ISO 5347 (Methods for the calibration of vibration and shock pick-ups) series of standards as part of its standards review program.

2. AN OVERVIEW OF ISO 16063 STANDARDS

At the time of writing this paper, the ISO 16063 "Methods for the calibration of vibration and shock transducers" series of standards consisted of 8 parts (including the preliminary work item part 41) relating to calibration methods for vibration and shock transducers. The parts of the standard are:

- ISO 16063-1:1998, Ed. 1, Part 1: Basic concepts [1].
- ISO 16063-11:1999, Ed. 1, Part 11: Primary vibration calibration by laser interferometry [2].
- ISO 16063-12:2002, Ed. 1, Part 12: Primary vibration calibration by the reciprocity method [3].
- ISO 16063-13:2001, Ed. 1, Part 13: Primary shock calibration using laser interferometry [4].
- ISO 16063-15, Ed. 1, Part 15: Primary angular vibration calibration by laser interferometry [5].
- ISO 16063-21:2003, Ed. 1, Part 21: Vibration calibration by comparison to a reference transducer [6].
- ISO 16063-22:2005, Ed. 1, Part 22: Shock calibration by comparison to a reference transducer [7].
- ISO 16063-41, Part 41: Calibration of laser vibrometers (preliminary work item) [8].

With the exception of parts 13, 15 and 41, the ISO 16063 standards are revisions of parts of the ISO 5347 series of standards. For instance ISO 16063, part 11 is the revised version of part 1 of ISO 5473.

Following is an overview of these standards. The information provided should be considered for information purposes only. For detailed information the actual standard should be consulted.

2.1. ISO 16063 Part 1

Part 1, "Basic concepts", was prepared by the Technical Committee ISO/TC108 and constitutes a minor revision of ISO 5347-0:1987. The standard describes methods for the calibration of vibration and shock transducers including methods for the measurement of transducer characteristics in addition to the transducer sensitivity. This standard recommends preferred methods which have been proven to produce reliable results when applied to rectilinear acceleration, velocity or displacement transducers.

The content of the standard covers terms and definitions, characteristics to be measured, calibration methods, as well as the expression of uncertainty of measurement. The standard lists ISO 1101: 1983, ISO 2041:1990, ISO 2954:1975 and the GUM as normative references.

2.2. ISO 16063 Part 11

Part 11, "Primary vibration calibration by laser interferometry" is a technical revision of ISO 5347-1 and replaces that standard. The measurement scope of the standard is listed in table 1 below.

Table 1. ISO 16063-11 measurement scope

Parameter	Range
Frequency range	1 Hz to 10 kHz
Acceleration amplitude	0,1 m/s^2 to 1 000 m/s^2

The standard specifies three different laser interferometry techniques to be implemented to achieve primary calibration of vibration transducers;

- Method 1: The fringe-counting method that is generally applied to determine the sensitivity magnitude over the frequency range 1 Hz to 800 Hz.
- Method 2: The minimum-point method that can be applied to determine the sensitivity magnitude over the frequency range 800 Hz to 10 kHz.
- Method 3: The Sine-Approximation method that can be applied to determine the sensitivity magnitude and/or phase over the frequency range 1 Hz to 10 kHz.

The content of the standard covers the uncertainty of measurement (listed in table 2), the apparatus requirements, ambient conditions, preferred accelerations and frequencies as well as a test procedure for each method. In Annex A, uncertainty components relating to the three methods are listed, while formulae for the calculation of acceleration are listed in Annex B.

Table 2. ISO 16063-11 uncertainty of measurement limits

Parameter	Uncertainty of measurement
Magnitude sensitivity at reference conditions	0,5 %
Magnitude sensitivity outside reference conditions	≤ 1 %
Phase shift of sensitivity at reference conditions	0,5°
Phase shift of sensitivity outside reference conditions	≤ 1,0°

2.3. ISO 16063 Part 12

Part 12, "Primary vibration calibration by the reciprocity method" describes the procedures to be followed for the primary calibration of accelerometers using the reciprocity method and the SI system of units. The measurement scope of the standard is listed in table 3.

Table 3. ISO 16063-12 measurement scope

Parameter	Range
Frequency range	40 Hz to 5 kHz
Acceleration amplitude	10 m/s^2 to 100 m/s^2

The content of the standard covers the uncertainty of measurement (see table 4 for detail), applicable symbols, the apparatus requirements, ambient conditions, preferred amplitudes and frequencies as well as a description of the test procedure to be followed. The standard describes the calculation of the expanded uncertainty in Annex A. Annex B deals with the "Application of the theory of reciprocity to the calibration of electromechanical transducers".

Table 4. ISO 16063-12 uncertainty of measurement limits

Parameter	Uncertainty of measurement
Magnitude sensitivity at reference conditions	0,5 %
Magnitude sensitivity outside reference conditions	1 %
Phase shift of sensitivity at reference conditions	1,0°
Phase shift of sensitivity outside reference conditions	2,0°

2.4. ISO 16063 Part 13

Part 13, "Primary shock calibration using laser interferometry". In this standard shock sensitivity, S_{SH}, is defined as the relationship between the peak values of the accelerometer output quantity and the acceleration. The standard specifies a method based on the absolute measurement of the time history of the motion.

The standard describes the procedure to be used for primary shock calibration of accelerometers with the instrumentation required when using a laser interferometer to sense the time-dependent displacement during the applied shock. The content of the standard covers the uncertainty of measurement, apparatus requirements, ambient conditions, preferred accelerations and pulse durations, a description of the method and reporting of the results. Annex A to C provides an expression of the uncertainty of measurement, an explanation of the procedures and an alternative method of calculating the magnitude and phase shift of the complex sensitivity respectively.

A normative reference listed that deserves mentioning is ISO 5347-22, “Methods for the calibration of vibration and shock pick-ups” – Part 22: Accelerometer resonance testing – General methods.

2.5. ISO 16063 Part 15

Part 15, “Primary angular vibration calibration by laser interferometry” specifies the instrumentation and procedures to be used for primary angular vibration calibration of angular transducers as well as angular measuring instruments (rotational laser vibrometers). The standard is applicable over a frequency range from 1 Hz to 1,6 kHz and a frequency dependent dynamic range from 0,1 rad/s^2 to 1 000 rad/s^2 as listed in table 5 below.

Table 5. ISO 16063-15 measurement scope

Parameter	Range
Shock pulse duration range	0,05 ms to 8,0 ms
Dynamic range	10^2 m/s^2 to 10^5 m/s^2

The ranges specified in table 5 are covered with the uncertainty limits listed in table 6.

Table 6. ISO 16063-15 Uncertainty of measurement limits

Parameter	Uncertainty of measurement
Magnitude sensitivity at reference conditions	0,5 %
Magnitude sensitivity outside reference conditions	≤ 1 %
Phase shift of sensitivity at reference conditions	0,5°
Phase shift of sensitivity outside reference conditions	≤ 1,0°

Three primary methods (methods 1 to 3) are described, with two possible interferometer configurations (type A and type B) that may be implemented. The type A interferometer utilizes a retro-reflector as the measuring reflector, while type B interferometers utilize a diffraction-grating as the measuring reflector. Methods 1A and 1B uses a homodyne laser interferometer with the fringe counting method while methods 2A and 2B uses a homodyne laser interferometer with the minimum-point method. Methods 3A and 3B use a homodyne laser interferometer using the sine approximation method.

The content of the standard covers the uncertainty of measurement, apparatus requirements, ambient conditions, preferred angular accelerations and frequencies, method descriptions using fringe counting, minimum-point and sine approximation, which include the expression of the results.

Annex A covers the components to be considered for the uncertainty of measurement estimation while Annex B deals with the formulae relating to the calculation of angular quantities.

2.6. ISO 16063 Part 21

Part 21, “Vibration calibration by comparison to a reference transducer”. The standard describes the comparison calibration of vibration transducers over the frequency range from 0,4 Hz to 10 kHz.

The content of the standard covers the uncertainty of measurement (listed in table 7), apparatus requirements and ambient conditions (listed in table 8). In the section relating to calibration, preferred amplitudes and frequencies are stipulated as well as measurement requirements, the calibration procedure and the expression of results. The final section in the standard relates to the reporting of the calibration results.

Table 7. Attainable uncertainties of magnitude and phase shift of the complex sensitivity as per ISO 16063-21.

Parameter	Example 1	Example 2
Magnitude		
Accelerometers (0,4 Hz to 1 kHz)	1 %	3 %
Accelerometers (1 kHz to 2 kHz)	2 %	5 %
Accelerometers (2 kHz to 10 kHz)	3 %	10 %
Displacement and velocity transducers (20 Hz to 1 kHz)	4 %	6 %
Phase shift		
At reference conditions	1°	3°
Outside reference conditions	2,5°	3°

Two different applications of the standard are referred to in the standard. Example 1 is applicable for applications where the reference transducer is calibrated by primary means. Example 2 is applicable for applications where the reference transducer is not calibrated by primary means, but has a traceable calibration.

Table 8. Environmental conditions specified in ISO 16063-21.

Environmental conditions	Example 1	Example 2
Laboratory temperature	(23 ± 5) °C	(23 ± 10) °C
Relative humidity	75 % max.	90 % max.

2.7. ISO 16063 Part 22

Part 22, “Shock calibration by comparison to a reference transducer” describes the secondary shock calibration of accelerometers using a reference acceleration, velocity or force measurement for time-dependent shock. The measurement scope of this standard is listed in table 9.

Table 9. ISO 16063-22 measurement scope

Parameter	Range
Shock pulse duration range	0,05 ms to 8,0 ms
Dynamic range	10^2 m/s^2 to 10^5 m/s^2

The limits of the uncertainty of measurement using this standard are listed in table 10.

Table 10. ISO 16063-22 Uncertainty of measurement limits

Shock calibration apparatus	Peak acceleration	Minimum pulse duration	Uncertainty limit
Pendulum	1,5 km/s^2	3	5 %
Dropball	100 km/s^2	0,1	5 %
Pneumatically operated piston	100 km/s^2	0,1	5 %
Hopkinson bar (velocity comparison)	100 km/s^2	0,05	10 %
Hopkinson bar (acceleration comparison)	100 km/s^2	0,05	6 %
Split Hopkinson bar (force comparison)	100 km/s^2	0,05	10 %

The content of the standard also covers apparatus, ambient conditions, preferred accelerations and pulse durations, method description and the reporting of results.

Annex A deals with the uncertainty of measurement with some uncertainty examples given in Annex B.

2.8. ISO 16063 Part 41

Part 41, "Calibration of laser vibrometers" is in the process of being developed by Technical Committee ISO/TC108, Subcommittee 3.

3. IMPLEMENTING AN ISO STANDARD

The advantages of implementing an ISO standard for the calibration of vibration transducers were investigated. For illustration purposes, the implementation of ISO 16063-11 is discussed in some detailed.

Various techniques and systems were examined for extending the CSIR National Metrology Laboratory's (NML) primary accelerometer calibration facility in the late 1990's. The system in use at the time, a homodyne HeNe laser interferometer system, employing the well established ratio-counting method, provides the NML with primary acceleration calibration capabilities (magnitude only) over the frequency range 40 Hz to 1 kHz. After careful consideration, the sine-approximation method was selected for extending the calibration range up to 10 kHz [9].

In order to do away with the costly and tedious task of developing a procedure that would measure up to international scrutiny, ISO 16063-11 was adopted by the NML. A primary calibration system, based on method 3 – sine approximation, was developed in conformance with said standard.

Developing calibration systems conforming to ISO 16063 has many advantages. These advantages relate to

- the actual method development
- apparatus and the apparatus requirements
- the achievable scope of calibration and uncertainty of measurement limits
- requirements for environmental conditions
- test procedure development

3.1 Method development

ISO standards are developed by international experts in the related field. The standards incorporate current best practice ensuring state of the art methods are employed, which will be widely accepted if implemented in conformance with the standard. The time and expertise devoted to the development of a single standard cannot be compared with the cost of purchasing the relevant standard from ISO, nor can an individual institute cost effectively develop an equivalent procedural method, with similar acceptance in the international community. When all the above factors are considered, an ISO standard is an extremely cost effective investment, in terms of monetary value and time.

3.2 Apparatus and the apparatus requirements

Section 3 of the ISO 16063-11 standard describes in detail the requirements of the apparatus required to implement primary vibration calibrations systems for any of the 3 methods described. The apparatus and its requirements are discussed in as many as 15 subsections. Such detailed knowledge of the requirements of the apparatus needed to establish the primary method, empowers the laboratory to effectively acquire the necessary equipment and adequately prepare the laboratory.

3.3 The achievable scope of calibration

The first section in each of the ISO 16063 series of standards defines the scope of the standard. Very relevant aspects described within the scope of the standard are the ranges, both in terms of the frequency range and acceleration amplitude, applicable to the implementation of the method described in said standard. For the laboratory interested in developing a primary accelerometer calibration facility, the scope, in combination with the uncertainty of measurement limits, are the first parameters to be considered when selecting the appropriate method or standard to implement. These parameters indicate whether the method described in the standard will meet the requirements of the laboratory.

These applicable ranges and uncertainty limits have been established through practical implementation by the standards developers, therefore assuring the implementing laboratory that the scope is achievable. Whereas if the laboratory where to develop its own method, the scope would have to be experimentally determined.

3.4 Requirements for environmental conditions

With the environmental conditions requirements specified, the laboratory can adequately prepare the laboratory environment with respect to temperature and humidity control for the optimal implementation of the method.

3.5 Test procedure development

Second to the development of a measurement methodology (in this example, quadrature laser interferometry with sine approximation signal processing), is the development of the actual test method which is certainty the most challenging aspect of developing a vibration calibration system. By implementing a calibration system based on ISO standard, the laboratory can draw on the expertise and experience of leaders in the field concerned, viz. primary vibration calibration by laser interferometry. Further more, the methods described in the standard have already been scrutinized and accepted by 156 ISO member countries [10] when published.

ISO standards are not prescriptive as far as the actual system configuration is concerned. Consequently, systems developed by different institutions, in compliance with the same standard, may differ considerably. Part 11 of ISO 16063 provides the user with detailed formulae (see Annex B [2]) to enable the scientific principles, applicable to the test method, to be fully understood by the user.

4. CONFORMANCE TO ISO 16063-11

An institute wishing to take advantage of the aforementioned advantages of implementing an ISO standard is faced with the responsibility of proving compliance with the standard implemented. Without this proof of compliance, the institute will not be in a position to quote the system performance specification as laid down in the ISO specification in question.

With the implementation of ISO 16063-11, utilizing apparatus with manufacturer's specifications that meet the requirements specified by the standard is sufficient proof of compliance to that specific aspect of the standard. Overall conformance to the uncertainty limits could however only be demonstrated through comparison measurements with other NMI's.

5. CONCLUSIONS

ISO standards are not intended to provide a "recipe" for the implementation of systems. They provide guidance with regard to apparatus and other requirements and provide a uniform approach to the method implementation so that institutes obtain equivalent measurement results globally.

Within the framework of an ISO standard, individual institutes can develop vastly different system configurations with comparable results.

Apart from the promotion of standardized measurement method implementation which leads to comparable measurement and calibration results, the implementation of ISO standards has significant scientific and financial benefits for the user.

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