DEFINING A NEW CALIBRATION BENCH FOR ACOUSTICAL INSTRUMENTS

PACS Reference: 43.58.Fm, 43.58.Vb

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ABSTRACT

In this paper, important improvements in acoustical instrument's calibration are presented. The design of a new calibration bench, based in PXI technology, is discussed. With this system verification and calibration of sound level meters, integrating-averaging sound level meters and sound calibrators can be accomplished. This bench has been specifically designed to test sound level meters which are submitted for control by legal metrology services. Calibration can be performed manually, through an RS-232 or GPIB interface, or with the help of Machine Vision technologies.

INTRODUCTION

Society is giving an increasing importance to many acoustical measurements, such as the ones related to noise pollution. Many regulations about these types of measurements are being developed around the world. One of the most important aspects of these regulations is about the legal metrology control of the instrumentation used to perform these measurements. A measurement can only be taken into account if the instrumentation used is in good conditions. But, what does it mean to be "in good conditions" for an instrument? The answer to this question is called verification.

One of the most popular instruments for performing a wide range of acoustical measurements is the sound level meter. Verifying a sound level meter (SLM) consists in performing a set of tests that guarantee the SLM specifications conform to some international standard within given tolerances. Different tests must be performed to evaluate each SLM characteristic. Some of these tests are carried out acoustically, applying acoustical signals to the SLM, and some electrically, substituting the microphone for an equivalent impedance and applying electrical signals to the SLM electrical input. These tests are usually performed conforming to the standards indicated in references [1] and [2].

A sound level meter is always used together with a sound calibrator, that is, a sound device designed to produce a known effective sound pressure level or levels at a specified frequency or frequencies when coupled to specified types of microphone in specified configurations. Therefore, when a SLM is submitted to the control of Legal Metrology Services, it is always accompanied by its sound calibrator. Sound calibrators are verified conforming to the international standard referenced in [3].

Nowadays only a few commercial systems are available for calibrating sound level meters, and most of them use quite old technologies. Usually they are based in a set of bench top instruments connected to a computer by means of some interface bus, such as the IEEE-4888 bus, and a software application that runs in the computer to automate these tests. But at the end, most of the tests are carried out manually, meaning that the operator must enter the SLM readings in the computer through the keyboard. These systems are usually slow and bulky so a single instrument verification can take up to four hours. In order to reduce test duration, some manufacturers are incorporating the possibility of executing some tests with the help of a multimeter or even recently, using RS232 interfaces as it will be explained here. In this paper the design of a new calibration bench based in PXI technology is presented.

VERIFICATION PROCEDURES

Table 1 shows an extent of the procedures for verification of sound level meters, integrating-averaging sound level meters and sound calibrators according to the recommendations of the *International Organization of Legal Metrology*, [4] through [6]. In the left column the characteristics of a SLM to be tested are presented; in the middle column, the ones for an integrating-averaging SLM; and in the right column, the ones for a sound calibrator. In all cases the clauses of the corresponding standards, [1] trough [3], are included.

SLM	Integrating-Averaging SLM	Sound Calibrators
Acoustical properties: ▪ A.1 Indication under reference conditions (4.2, 9.1, 9.2.1) ▪ A.2 Relative free-field frequency response in the reference direction (frequency weightings) (4.4, 6.1, 9.1, 9.2.2) ▪ A.3 Relative free-field frequency response with accessories (10.1, 11.2.14) ▪ A.5 Frequency, sound pressure level and distortion of a sound calibrator (4.2, 9.2.1, see also OIML R 102)	Acoustical properties: ▪ A.1 Indication under reference conditions (4.2, 9.1, 9.2.1) ▪ A.2 Relative free-field frequency response in the reference direction (frequency weightings) (4.4, 6.1, 5.1, 9.1, 9.2, 9.2.2) ▪ A.3 Relative free-field frequency response with accessories (10.1, 11.2.14, 11.2.15) ▪ A.5 Frequency, sound pressure level and distortion of a sound calibrator (4.2, 9.2.1, see also OIML R 102)	Acoustical and electrical properties: ▪ A.1 Sound pressure level(s) when coupled to specified microphone(s) in specified configurations or to a given model of sound level meter (under reference ambient conditions) (2.2, 2.3, 2.4, 3.1 and 3.7) ▪ A.2Harmonic distortion (3.4 ▪ A.3 Frequency (3.2) ▪ A.4Tone-burst capability (if applicable) (3.5)

Electrical properties: ▪ A.6 RMS detector (7.2, 9.4.2) ▪ A.7 Time weighting (S, F, I, Peak) (4.5, 7.2-7.5, 9.4.1, 9.4.3, 9.4.4) ▪ A.8 Level range control (6.3, 6.4) ▪ A.9 Indicator (7.6-7.10) ▪ A.10 Overload indication (6.5, 9.3.1)	Electrical properties: ▪ A.6 RMS detector (7.2, 9.4.2 of IEC 651) ▪ A.7 Time weighting (S, F, I, Peak) (4.5, 7.2-7.5, 9.4.1, 9.4.3, 9.4.4 of IEC 651) ▪ A.8 Level range control (5.2, 6.4, 9.3.1) ▪ A.9 Indicator (6.3, 6.4, 6.6 of IEC 804; 7.6 - 7.10 of IEC 651) ▪ A.10 Overload indication (6.5, 9.3.1) ▪ Linearity range (3.5, 6.2, 9.3.3) ▪ A.14 Pulse range (6.2, 9.3.4) ▪ A.15 Overload indication (4.6, 7, 9.3.5 of IEC 804; 6.5, 9.3.1 of IEC 651) ▪ A.16 Time averaging (4.5, 6.1, 9.3.2) ▪ A.17 Average AI-weighted SPL (Appendix B)	(if applicable) (3.5)

Table 1. Extent of the procedures for verification of SLM, Integrating-Averaging SLM and Sound Calibrators.

As it can be seen in table 1, international standards allow performing some of the tests electrically, while the rest must be performed acoustically. In the electrical tests the microphone is substituted by an equivalent impedance and electrical signals are applied to the SLM as the excitation. In the acoustical tests, acoustical signals are directly applied to the SLM through its microphone. In any case the SLM response to those signals has to be checked by the computer.

The main problem of these procedures is that they make verification long and tedious. Many tests have to be performed, and most of them require a considerable amount of time. For example, in the linearity test, the response of the SLM has to be checked at different frequencies for amplitudes covering the complete instrument range in 0.1dB and in 10 dB steps. For an instrument with a 60 dB range tested at 6 different frequencies, this means taking 3600 readings of the SLM. And that's only one of the tests to be performed! This means that the way these readings are obtained is a key point in SLM verification.

<u>Obtaining SLM's Readings</u>

Traditionally the operator has been the one responsible for taking these readings. He had to be in front of the SLM following the instructions given by the computer program that runs the verifications tests. Once a stimulus is applied to the SLM, the operator is asked to enter the SLM's reading in the computer through the keyboard. This, of course, is time consuming. But most of all, it is ridiculous. The operator must observe thousands of readings to verify a single SLM. This will mean incorrect results due to the operators fatigue and long verification times.

<u>Using the dc output</u>

The first way of solving the problem is by using a voltmeter connected to the DC output of the SLM. The DC output of a SLM provides a voltage proportional to the reading of the SLM. Once the relation between this voltage and the reading is known, a voltmeter can be used to measure the voltage and then convert it to the corresponding reading in the computer. So another test must be introduced before any of the electrical tests shown in table 1, which determines the relation between the DC output of the SLM and its reading. As this relation is usually linear, for many manufacturers the result of this test is simply the sensitivity of the DC output.

This method of obtaining the SLM's reading works quite well with many instruments, but has the following problems:

- Unfortunately, not all SLM have a DC output.
- The DC output of the SLM cannot be used in all tests. In most cases, the DC output is proportional to the some of frequency weighted “F” or “S” time-weighted sound level. If that is the case, it can only be used in those tests where the frequency weighted “F” or “S” time-weighted sound level is being measured.

<u>Using the RS-232 interface</u>

Another way of obtaining the reading of a SLM is by using its RS232 interface, if available. Some SLM have an RS-232 interface to connect them to a computer. Traditionally this interface has been used for interfacing the SLM with a printer, or to download the measurement results to a computer at the end of a measurement process. But it can also be used during verification.

When an instrument is provided with a programmable interface, such as RS-232, a command set for the instrument must be developed. This set of commands allows controlling the instrument from a computer as it would be done by pushing the buttons in its front panel. If all functions can be controlled through this interface, it can be used during verification both to configure the SLM and to get the corresponding readings. For this to be possible, the command set of the instrument must include enough commands as to control all of the SLM characteristics.

This is the ideal solution and of course the best of all. With an appropriate set of commands this would allow a 100% automation of the electrical tests: the computer sends commands to configure the SLM, then sends commands to the instruments to apply the corresponding stimulus and the queries the SLM for its readings. At the end it compares the readings of the SLM with the values of the standard and decides whether it passes the test or not. This is repeated for all tests, so the full process can be accomplished almost without the need of an operator. Of course an operator must be present to supervise the process, to make the connections needed and to complete the acoustical tests.

The requisites for this to be possible are the main problem here.

- Many instruments do not have a programmable interface.
- Even between those who have this kind of interface, many of them don not have a complete command set. Some operations can be done, but others can’t.
- And even worst, some manufacturers do not provide at all the command set for their instruments. They just provide a software application to connect the instrument to a computer and download the measurement data, but they do not provide the command set. This must be because traditionally this command set hasn’t been used at all.

<u>Using machine vision</u>

The last option to obtain the reading of a SLM during verification is through machine vision, as it was presented in [7]. This approach requires a camera to get a picture of the SLM reading. Then with an image acquisition card the image is acquire in the computer. Using machine vision algorithms the reading of the SLM can be obtained from the image. If this is implemented appropriately the whole process takes a few milliseconds, so it can be done in “real time”.

This solution overcomes any limitation of the SLM in terms of its outputs, as all SLM must have a display. So with appropriate algorithms it can be used with almost any SLM. There are two types of SLM displays: 7 segment based displays and dot displays. Different algorithms must be used depending on the type of display.

This approach has also another advantage, which is that it can be used in any operation mode of the SLM, as in any mode the reading must be presented in the SLM’s display. It is just as obtaining the reading with the help of the operator, but substituting the operator’s eyes by “a computer eye”. The computer does not get tired and it behaves always the same way.

Electrical tests

Electrical tests are performed substituting the microphone of the SLM by equivalent impedance and applying electrical signals to the SLM through this impedance. The types of signals used depend on the specific test, and their levels depend on both the test and the SLM's characteristics. Types of signals include sinusoidal, sinusoidal single bursts, sinusoidal repetitive bursts and rectangular impulses. When it is not possible to generate all types of signals with a signal generator some systems use some kind of waveform conformer together with the signal generator. This conformer usually includes a high precision attenuator to permit to generate all possible signal levels.

Table 2 shows the signals levels in volts that must be generated for different SLM models and the resolution for 0.1dB steps. As it can be seen from the table, the dynamic range of the instrument used to generate these signals must be very wide (>125 dB), while maintaining a very good resolution. The best way to accomplish this is to use a high precision signal generator together with a high precision attenuator.

Manufacturer	Model	Sensitivity	Range (dB)		Range (V)		Resolution (µV)
		(mV/Pa)	Min.	Max.	Min. (µV)	Max. (V)	(0,1 dB)
O1 dB	Symphonie	50	32	135	39	5,62	1,01
Bruel & Kjaer	BK2236	36,6	23	140	10	7,32	0,74
	BK2237	31,6	30	140	19	6,32	0,64
	BK2238	36,6	23	140	10,3	7,32	0,74
	BK2260	50	22	130	12	3,16	1,01
Cesva	SC-2C	13,5	30	130	8	0,85	0,27
	SC-20	16	30	137	10	2,27	0,32
	SC-15C	13,5	26	137	5,3	1,91	0,27
Rion	NL-05	22,38	29	139	12	3,99	0,45
	NL-15	39,8	27	140	17	7,96	0,81
	NL-18	39,8	20	140	7	7,96	0,81
	NL-27	39,8	30	140	25	7,96	0,81

Table 2. Signal levels for different SLM models.

For sound calibrators a distortion analyzer must be used as well to measure the distortion of the instrument.

Acoustical tests

In the acoustical tests, acoustical signals are directly applied to the SLM through its microphone. These tests require generating a reference signal at a given level and frequency, and varying its frequency over a predetermined frequency range. To generate these signals a multifunction acoustical calibrator is usually used.

At the end of all tests an overall system calibration is preformed in order to adjust the SLM to the correct microphone sensitivity.

SYSTEM DESCRIPTION

The heart of the system has been developed with PXI products from National Instruments. PCI eXtensions for Instrumentation (PXI) modular instrumentation delivers a PC-based, standardized, high-performance measurement and automation system at an affordable price. PXI benefits from the low cost, ease of use, and flexibility of PC technology by using open industry standards. PXI combines the high-speed PCI bus with integrated timing and triggering to deliver a more than 10X performance improvement over older architectures.

The system's architecture consists of the following elements:

- A PXI mainframe (NI PXI-1002 or NI PXI-1000B) that holds the following instruments:

  - An arbitrary function generator (NI PIX-5431) and a high precision attenuator for generating the electrical signals needed in the electrical tests. By using an arbitrary function generator any kind of signal can be generated. The high precision attenuator adapts the dynamic range of the generator output to the different signals levels needed depending on the SLM model and the range being tested.

  - A 6½digits multimeter (NI PXI-4460) to measure the DC output of the SLM. If the DC output method for obtaining the SLM's reading is preferred, the multimeter enables this option.

  - An image acquisition system consisting of a camera (Pullnix PE20) and an image acquisition board (NI PXI-1408) used to obtain the SLM's reading.

  - A computer that runs a software application developed in LabVIEW that controls the system. The computer can be an embedded computer (NI PXI-8174), making the system fully portable, or a desktop computer connected through an interface board (PXI-PCI8330) to the PXI chasis.

  - A communications interface unit. This module provides an RS-232 and IEE-488 interface for controlling SLM's and an Ethernet interface to connect the calibration system to a central calibration data base server. Depending on which type of computer is used (embedded or external) It can be implemented within the computer (NI PXI-8174) or with an interface board (NI PXI-8212).

  - A dynamic signal analyzer (NI-PXI 4472) used to perform distortion measurements during sound calibrators' verification.

  - An environmental conditions measurement unit (ALMEMD 3290) for monitoring temperature, relative humidity and pressure values during verification.

- A multifunction sound calibrator (BK 4226) used in the acoustical tests.

The system has the following characteristics. Verification of SLM and integrating-averaging SLM can be done in four different modes depending on how the reading of the SLM is obtained: manual, semi-automatic DC (DC output), semi-automatic Vision (machine vision) or automatic (RS-232 or IEEE-488). All tests conform to the corresponding IEC standards in use, but the system is fully prepared to meet the upcoming proposed standards which will replace current ones, [1] through [3]. As a result of the process a verification or calibration report is automatically generated using Microsoft Word.

CONCLUSIONS

When specifying a calibration bench for sound level meters special attention must be paid to the way the reading of the SLM is obtained. In fact it is one of the most important parts in defining the system. As far as is concerned for verification, the ideal situation would be that all SLM would have a programmable interface, such as RS232 or IEE 488, and a complete command set. This would allow full automation of the verification process and it would reduce uncertainty, as it wouldn't be necessary to include any contributions from the measuring instruments. Nowadays manufacturers are not playing much attention to this aspect of the SLM, so at the moment this can only be done with a few instruments. The DC output method can be used with some instruments, but is usually restricted to just a few tests. This is because this output normally follows only some of frequency weighted "F" or "S" time-weighted sound level so tests that must verify other capabilities of the SLM cannot use this output. The "machine vision" alternative can be used with any SLM and in any test.

With respect to the rest of the instrumentation needed, it must be noted that the wide dynamic range needed and the different types of signals that must be generated, recommend that an arbitrary signal generator is used together with a high precision attenuator.

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