Understanding Instrument Calibration

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ABSTRACT

Calibration is often misunderstood and is filled with many misconceptions. Neither the users of instruments nor the simple laboratories that perform the calibration assessmnets have a clear understanding of their roles in the complex field of calibration. This article provides the necesary processes involved in calibrating an instrument, simple or complex, and a brief description that wil clarify the myriad misconceptions.

1 INTRODUCTION

Often people ask a calibration laboratory to either "calibrate" their instruments or to tell them details that are involved in calibration. Further, certificates, that claim cali-bration, are often missing details that provide a level of con-fidence that the instrument was sufficiently checked (and maybe adjusted) to assure it measures correctly. The follow-ing paragraphs provide some of the important concepts that are "required knowledge" by an engineer or technician do-ing acoustical or vibration measurements.

2 CERTIFICATE ISSUES

Calibration certificates can come as a stand-alone document, or more correctly, with a report of the results. If it is the latter, the certificate acts as a summary page, perhaps with certain details, attesting to the results found in the report. If the former, the test results must be on the certificate or must be referred to another, non-distributed document. There are no standard requirements for a certificate, and in fact, one isn't needed if other documentation is provided.

It is clear that the wording on some certificates cannot and should not, be considered as adding any information or authenticity to the service provided. Wording on the certifi-cates may be confusing or intentionally misleading. The instrument owner must be prepared to interpret the informa-tion that some statements give and eventually to require further proofs.

Here are some examples:

2.1. NIST related

a) Calibration is traceable to NIST. This gives the impression that NIST has something to do with the certificate and its only relationship, if any, is that it has measured something that the laboratory has used the data from. See below for further discussion. In the same category is the "NIST traceability number ...." whose signifi-cance can only be guessed, as it is not a metrology term and it is not defined in international documents.

b) Certificates stating "meets NIST requirements" also do not convey any useful information. NIST itself has no requirements, although NIST's National Voluntary Laboratory Accreditation program (NVLAP,) a pro-gram for calibration laboratories, has strict require-ments. (See below.)

c) Advertisements claim NIST certificate provided. The only way this can be is if NIST does the calibration, which is very unlikely.

2.2 Accreditation related

Accreditation is a process where a laboratory is checked by an outside party for, in this case, quality. The main purpose is, if one believes the outside party's reputation, that cus-tomer can have some assurance that the calibration labora-tory's quality is adequate and one need not check it. So ac-creditation is useful if the customer has neither the skills nor the time to check on a calibration laboratory.

a) Claims of ISO 17025 [1] accredited or ISO 9000 ac-credited. This can be a legitimate and important state-ment if the customer knows which accrediting agency did the accreditation. It cannot be self accredited.

b) ISO 17025 compliant means, usually, the laboratory claims it meets ISO requirements because it follows the standard. No neutral body audited the laboratory. This may or may not point to a good laboratory.

2.3. Examples of other issues

Often certificates have verbiage that sounds better than it is. Here are some examples:

a) Instruments calibrated to ANSI or IEC standard without specifying either standard designation or date of standard.

b) Statements that measurements made in strict accor-dance

with (or to) a standard. Few laboratories meet all requirements in a standard (for instance, how many laboratories check range of operating temperatures?)

c) An instrument under test meets manufacturer's specifications. Often this is all that can be done, especially if no claim is made for meeting a recognized standard. In which case the laboratory must state the exact specifications and the results, to show they lie within specs. But often specs are vague (frequency range is from 20 Hz to 20,000 Hz) or specifications are different depending on what manufacturer's brochure one looks at: data sheet, instruction manual, etc., and what date it is published.

d) Calibration due dates (often but arbitrarily yearly) are specified on sticker or cal certificate. This is not generally allowed under conformance with ISO 17025 and can only be specified based on instructions of customer. The issue of calibration intervals (discussed below) is very important and often prescribed, incorrectly so it seems, in legal statutes. In that case, the calibration in-terval must be met.

3 CALIBRATION

Calibration is defined as a set of operations that establishes, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or reference material, and the corresponding values realized by standards [2]. In other words, the calibration determines the values of the errors of a measuring instrument (and if necessary, determines other metrological properties as well). As a result of the calibration, a test/calibration report with the test results is issued, which should be eventually accompanied by a calibration certificate, confirming that the necessary procedures have been carried out to ensure their validity and traceability. (VIM and ISO Guide 30 [3]. See also ISO Guide 31 [4]).

According to these definitions, the calibration is not re-quired to provide a statement about compliance with ac-cepted specifications. Nevertheless, in order to help the us-ers, Scantek, Inc. provides "pass" or "fails," when appropri-ate, in the terms defined by ISO 17025. If reliable specifica-tions are not available, then no statement of compliance is made.

Calibrations may include adjustments, always reported, to correct any deviation from the value of the standard, but this is not covered by the definition of the service.

4 TRACEABILITY

The definition of traceability is "the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons, all having stated uncertainties." [2] An unbroken chain of comparisons is a complete, explicitly described, and documented series of comparisons that successively link the value and uncertainty of the result of a measurement with the values and uncertainties of each of the intermediate reference stan-dards and the highest reference standard to which traceabil-ity for the result of measurement is claimed. In other words, from the best (international standard, a national laboratory) to the calibration laboratory, all uncertainties must be ac-counted for and utilized to express laboratory's uncertainty. Traceability insures the uniformity in time and space of the measurements (meaning that at any time and on any merid-ian the same measured parameter will have the same value).

It is important to note that traceability is the property of the result of a measurement, not of an instrument or calibration report or laboratory. Following any one particular procedure or using special equipment does not achieve it. Merely having an instrument calibrated, even by NIST, is not enough to make the measurement result obtained from that instrument traceable. The measurement system by which values are transferred must be clearly understood and under control.

To achieve and maintain traceability to the International System of Units (SI), a calibration laboratory must have implemented a quality system, environmental controls and increased competence so it complies with every one of the requirements listed in the IEC 17025 - 1999 standard.

Following are the key elements of the implemented traceability: a) reference standards calibrated directly by national laboratories or by other accredited laboratories that can prove traceability, b) use of validated procedures and test methods for all tested parameters, c) documented measure-ment conditions and uncertainties, which are reported with each measurements, d) internal measurement assurance pro-gram to insure maintenance of the quality of the standards and of the services provided, and e) competent personnel to perform service and calibrations.

The internal measurement assurance program is one of sufficient complexity, within an organization, to provide credibility to the measurement uncertainty and measurement result for which traceability is to be established. An internal measurement assurance program usually involves monitoring the performance (e.g., stability, and reproducibility) of the measurement system before and after it is used for calibrations.

5 ACCREDITATION

Laboratory accreditation - the procedure by which an authoritative body gives formal recognition that a laboratory is competent to carry out specific tasks. Accreditation does not itself qualify the laboratory to approve any particular product. However, accreditation may be relevant to approval and certification authorities when they decide whether or not to accept data produced by a given laboratory in connection with their own activities. (see ISO Guide 58 [6]).The laboratory accreditation, whether conducted by NIST/NVLAP or any other recognized accreditation body, is a finding of a lab-

oratory's competence and capability to provide scientifi-cally sound and appropriate measurement services within their scope of accreditation. Embedded in the process is an evaluation of the lab's ability to achieve and maintain trace-ability for the accredited services. Accreditation to ISO/IEC Guide 25, now replaced with international standard ISO/IEC 17025 determines that a laboratory has all of the necessary facilities, equipment, standards, procedures, uncertainty analyses, personnel, etc., which make it capable of provid-ing traceable measurement results. Laboratory accreditation speaks to the overall capability of a lab to provide the ser-vice. NIST experts often participate in the accreditation process, but the end result is a finding of competence and capability only it does not validate each particular result.

The fact that a laboratory is accredited does not necessarily mean that all tests provided are accredited. One must check the laboratory scope of accreditation, the presence of the accreditation body logo on certificate/report or a statement about type of tests, the presence of the measurement uncertainties…

This is what one laboratory, Scantek Inc., provides for various calibrations, some under the scope of accreditation, others not, as shown below.

5.1 Accredited Calibration Services

The measurements are performed using methods and procedures that have been assessed by NVLAP. The uncertainties reported for these measurements were also audited and rati-fied. This gives the highest degree of confidence that the measurements are accurate and traceable. It is possible that a calibration certificate and test report having the NVLAP logo contain tests that are not covered by the scope of ac-creditation. These tests are individually identified with the text: "not covered by the current NVLAP accreditation."

5.2 ISO 17025 -1999 Calibration Services

The compliant calibration services where test procedures comply with the requirements of the standard and were audited by an internal audit only. These are also traceable services that either were validated only after the NIST assessment or were not to be accredited. Calibration certificates for these services do not contain the NVLAP logo.

5.3 Ordinary Calibration Services

The services that are in various development stages, mostly with the measurement uncertainty budget not fully developed. One good example is the calibration of ISO 140-6 tapping machines where, to measure momentum, we do not possess traceable scales or dimensional gages.

5.4 Customized Calibration/Test Services

Special services where, upon request, special tests can be developed and provided. These can be selected from the existing tests w/o modifications, by customizing tests or by developing new ones. If agreed upon, the adapted or new procedures can be developed according to our Quality Sys-tem and be submitted to an internal audit. Only then, the traceability of the test results can be claimed. And a new assessment by NVLAP is required to incorporate this under Scantek's scope.

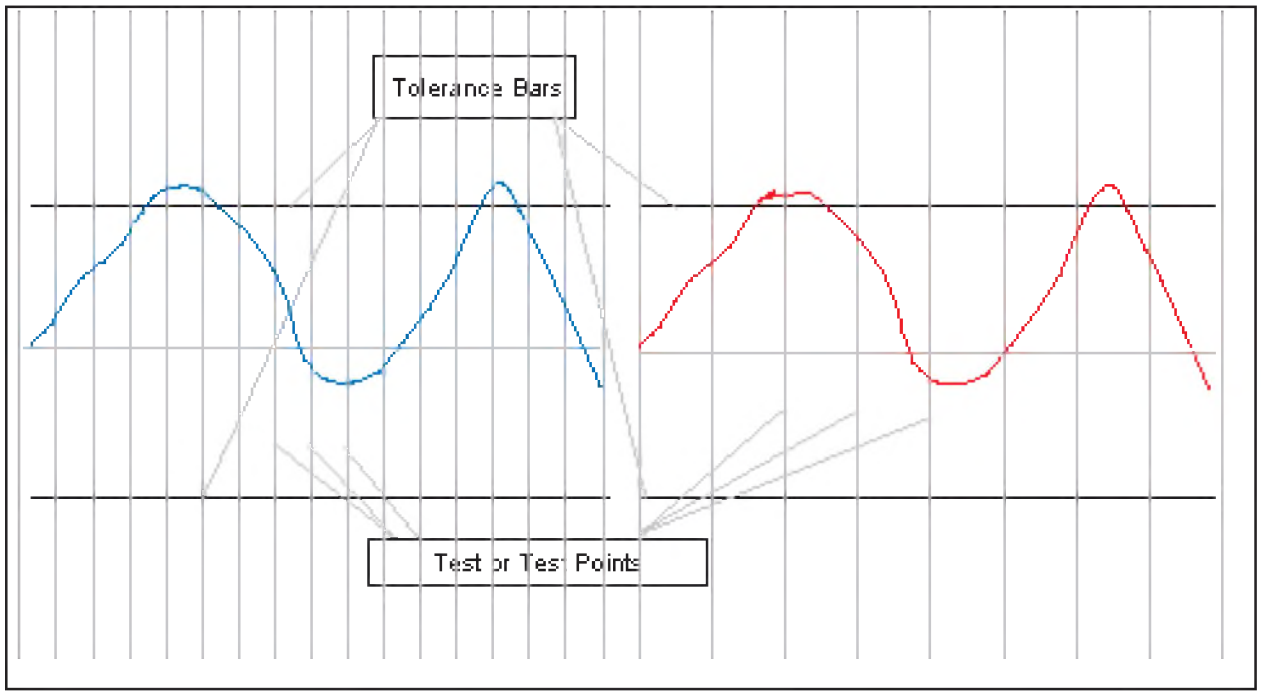

Figure 1. Influence on the frequency or numbers of test points on the confidence of calibration results: Left- Recommended by standards. Right- Reduced tests

6 PERIODIC CALIBRATIONS

There are two categories of calibrations: a) pattern evaluation (type testing) and b) verifications (periodic calibrations) The pattern evaluation contains the appropriate tests nec-es-sary to ascertain that an instrument entirely satisfies the re-quirements of the applicable standards. This means that eve-rything, all specifications, are checked in a sample of in-struments, and based on this sample, the "type" of the in-strument is verified. It validates both the design and the ca-pability of the instrument production line. This includes parameters such as temperature range, vibration tolerance, battery life, etc.

Periodic calibrations assure the user if that the performance of the instrument has not changed significantly from that determined in the initial tests. In order to ascertain that a meter is still within the requirements of the applicable stan-dards or specifications, one can perform all the possible tests or only test the main parameters. The consequence of one of the other of these choices is illustrated in a simplified intuitive manner in Figure 1 which shows that reduced tests could not catch the eventual out of tolerance condi-tions, thus reducing the confidence in the measurement re-sults. Normally, measurements performed in this manner should be reported with higher uncertainty. This figure shows also the difference between the standard calibration and basic calibration services that we use.

With increasing frequency, the newer instrumentation standards are including a more comprehensive list of the tests that should be performed for the periodic calibrations in order to be allowed to claim that the tested unit still com-plies with the standard.

7 CALIBRATION INTERVALS

Based on the ISO 17025 requirements, accredited laboratories do not provide a calibration interval on calibration sticker or certificate unless specified in writing by the cus-tomer and agreed by both parties. Nevertheless, based on the laboratory's experience, calibration history of customer's and similar instruments, and expected use of test instru-ments, the laboratory can help customers in establishing their own calibration intervals for the units they possess. Besides the manufacturer recommendations, which rarely are based on good data, recommended calibration intervals are based on calibration history (drift), use, and abuse of equipment, criticality of measurements, among other fac-tors. Perhaps the most useful factor is the unit's calibration history.

When a drift or a decrease of accuracy is not observed (which is often the case for the electronic equipment), then the decision about the length of the calibration interval must be based upon other aspects:

- age of the unit compared to the estimated lifetime of the class of instruments;
- calibration results for instruments grouped by model and manufacturer
- conditions of use of the instrument (risk of mishan-dling, overload, aggressive environment, mainte-nance/cleaning)
- sensitivity of the instrument parts to aggressive envi-ronment (for instance, the microphone is far more sen-sitive and fragile than the instrument itself)
- costs of damages if measurements are performed with an out-of-tolerance unit (fees, damage repair or cost of repeating the tests, loss of credibility)
- requested accuracy (the use of a type 1 unit when only a type 2 is needed reduces the risk of necessity of repeating the measurements even if the unit is out-of-tolerances)
- Calibration costs and frequency of use of the unit. The lack of use does not give insurance that the unit is within tolerances. Nevertheless, if the unit is rarely used one should be concerned about the efficiency of cali-brating the unit too often.

Finally, for reliable instruments, the frequency of the periodic tests is only determined by the need to obtain the proof or confidence that the instrument is within its known specifications.

As an example, for its own sound and vibration measuring instrumentation, Scantek, Inc. has established differentiated calibration intervals, in parallel with checks of functionality after each measurement in the field. The more sensitive instruments like calibrators, microphones, and accelerometers are more frequently calibrated (9-12 month) than the electronic instruments (1-1.5 years). Also, the very young and the very old units are checked every year. These intervals are updated after each calibration that revealed an out-of -tolerance condition.

8. SPECIFICS FOR THE CALIBRATION OF SOUND LEVEL METERS, DOSIMETERS, AND ANALYZERS

The calibration laboratory should offer calibration services to meet various needs of the customers, following the guidelines given in OIML R 58 [6] and OIML R 88 [7]. As required by the applicable standards, these complex units may be tested as systems, including the microphones and preamplifiers, or by components. The first approach is required for the pattern approval tests: acoustical methods and facilities (anechoic and reverberant rooms) are required. The test by components is used by the secondary laboratories like Scantek Inc., which do not possess anechoic rooms. The instrument is tested mainly using electrical methods. The global acoustical characteristics are calculated from the electrical responses and manufacturer provided corrections.

The test methods that most laboratories use for the sound

measuring instruments are detailed below, highlighting the aspects that may lead to confusions.

8.1 Microphones

Usually the pressure response at 250 Hz and the frequency response are determined. The latter is obtained either using the actuator method (which provides results equivalent to the pressure response) or by directly measuring the pressure response in a coupler. The other frequency characteristics (free-field for 0° incidence or diffuse field response) are cal-culated using the measured pressure response and the appli-cable corrections published by the manufacturer.

Here are some issues that are not discussed:

a. The credibility of the corrections is not verified

b. The corrections available from many of the manufac-turers have no uncertainties reported, which is sign of lack of traceability – (therefore we cannot claim trace-ability on the calculated characteristics)

c. The directivity of the microphone response is not checked.

8.2 SLM, Dosimeters, and Analyzers

Instrument parameters. The instrument is tested using electrical signals fed directly into the preamplifier through an adequate adaptor. The test signals are successively sine, continuous tone bursts, single tone bursts and, rectangular – all with various frequency and duration parameters. In this way, all main functions of the instrument are tested: input stages, weighting networks, time constant circuits, accuracy of calculated functions (Max., Leq, SEL, dose...).

Note that the standards require a long list of tests to be performed in order to allow the compliance claims. Performing tests using the methods published in the standards is not equivalent to a claim of compliance with the standard. Sec-ond, many laboratories perform only tests with sine signals. Testing the instruments only with sine wave will not charac-terize the response on the unit to impulsive signals. In nor-mal use, the instrument measures sounds, which are impul-sive most of the time. Ask about the content of tests within a calibration service in order to compare the providers or to establish a customized service to respond to your need and desired price. Testing the instrument accuracy at one frequency using a calibrator is not something that should be paid for….

Global characteristics of the instrument. The global acoustical characteristics of the instrument are calculated by combining the measured microphone and sound level meter re-sponses. Note that the directivity characteristic of the instrument is not tested at any time and corrections due to the instrument body are only added when available.

Dosimeters require not only regular tests as a SLM but additional tests in accordance with the dedicated standard. One should not be surprised of the higher calibration cost for dosimeters (unless the tests are sacrificed to obtain a lower price).

The octave and one-third octave band filter sets must be tested if present in the instrument. Again, the tests are per-formed using electrical method. The filter response is addi-tionally influenced by the frequency response of the meter – microphone included (one cannot expect to measure up to 20 kHz with an instrument who's frequency response falls after 12.5 kHz) even if the filters are present. In order to correctly use such a unit, one should use the calibration data in order to apply adequate corrections.

All instruments are tested in accordance with the manufacturer specifications. If the standard for which the manufacturer claims compliance is obsolete, the calibration will not upgrade the instrument to comply with a new standard, even if some tests are performed according to the new standards. No claim of compliance with a standard can be issued based solely on the periodic tests. A pattern evaluation test is required fore this.

9 CONCLUSIONS

The user of the instruments is required to make decisions about its instruments - from acquisition, calibration and maintenance, use and finally to removal from use. This paper attempts to provide details of some of the aspects related to the calibration of instruments and about responsibilities (calibration intervals, choice of laboratory and service type, use of instruments complying with the adequate standards, etc.). It must be noted, however, that this paper is neither comprehensive, nor exhaustive.

REFERENCES

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