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TRACEABILITY OF ACOUSTICAL INSTRUMENT CALIBRATION TO THE NATIONAL BUREAU OF STANDARDS

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Only a small fraction of the nation's acoustical measuring instruments can be calibrated at the United States' national standards laboratory, the National Bureau of Standards (NBS). Consequently, NBS acoustic calibrations are at present limited to essential and technically difficult areas of broad applicability, examples of which are the calibrations of measuring microphones. The critical needs of public and private acoustical calibration laboratories for state-of-the-art pressure and free-field calibrations are well established. To meet these far-ranging needs, an instrument calibration hierarchy has evolved comprising direct or implied chains of "traceability" to the NBS. Such "traceability" is not uniquely specified; for example, four possible definitions have been cited.[1] The current paper briefly describes NBS wideband microphone calibration services and pistonphone and acoustic calibrator calibration services, gives examples of the use of these NBS calibrations, and discusses examples of the traceability implicit in such use.

At the present time, the NBS offers fixed-cost services[2] for reciprocity-based pressure calibrations within the range 50 to 20,000 Hz of ANSI S1.12 type L ("one-inch")[3] and "half-inch" condenser microphones, and free-field calibrations by the reciprocity method of "half-inch" condenser microphones from 2500 to 20,000 Hz.[4] Special calibrations are performed at cost on pistonphones and acoustic calibrators by using NBS-calibrated microphones to measure the pressure they develop.

All of the NBS calibrations are ultimately traceable to fundamental standard measurements (e.g., mass, length, time, electric current) at the NBS. However, it should be noted that the accuracy of wideband microphone calibration is limited more by unique acoustical and electro-acoustical factors than by accuracy of measurement of fundamental constants.

Factors[4,5] influencing the accuracy of reciprocity calibrations include signal-to-noise ratio, stability of electronic instrumentation and the microphones themselves, and other frequency-dependent effects such as heat conduction, capillarytube, and wave-pattern corrections for pressure calibrations, or apparent acoustic center corrections and departure from ideal anechoic conditions in free-field calibrations. Complex and time-consuming procedures, including international interlaboratory comparisons when appropriate, and costly equipment (often designed and constructed for the purpose) are required to assess the effect of these factors and minimize their influence upon calibration accuracy. One can use only the reciprocity equations and a knowledge of the accuracy with which it is possible to determine fundamental and derived quantities to compute an estimate of the accuracy of a pressure calibration at midband frequencies. However, this estimate can be highly misleading, since it is not generally applicable unless one considers the above mentioned frequency-dependent factors. The ultimate validity of a wideband microphone calibration is primarily dependent upon the care and level of effort devoted over a period of years toward minimizing the influence of all of the factors limiting accuracy.

Users of the NBS calibration services include manufacturers of microphones and acoustical measuring instruments, calibration laboratories of Federal, state, and municipal regulatory agencies for occupational safety and environmental protection; metrology and calibration centers of the U.S. armed forces and their hearing conservation programs; university laboratories; major aircraft manufacturers for whom the economic consequences of regulatory compliance decisions are enormous; and private acoustical standards laboratories and consulting firms.

In general, different users of NBS calibration services may have different needs for the services, so that "traceability" is not the same concept for all users. In analyzing definitions of traceability, Belanger[1] described two contrasting views. One stresses "characteristics of measuring instruments or standards" and "regards accuracy as a property of an instrument," while a second "stresses requirements related to quantifying measurement uncertainty" and "focuses on the quality of the measurements themselves."

Examples of the first view include:

(i) Some laboratories send their pistonphones or other types of acoustic calibrators to the NBS for calibration. The calibrators are then used to provide quick or field-check calibrations (over a limited frequency band) of sound level meters or personal sound exposure meters (noise dosimeters).

(ii) Other laboratories calibrate their pistonphones and acoustic calibrators by measuring their reference sound pressures with microphones calibrated by the NBS. The current ANSI draft standard[6] for calibration of acoustic calibrators specifies use of NBS-calibrated type L or M microphones as the preferred method of determining the sound pressure produced by such calibrators.

(iii) Certain manufacturers of acoustical measuring instruments use NBS-calibrated microphones to establish the free-field sound pressures generated at a specified angle of incidence by a sound source in an anechoic chamber, and then use this field to calibrate their products.

(iv) Audiometric laboratories use microphones traceable to those calibrated by the NBS to measure the threshold of hearing for public health survey purposes, to establish the degree of hearing impairment and thereby determine the level of workmen's compensation for hearing loss, and to monitor the state of hearing of workers exposed to hazardous sounds. One of the armed services alone takes approximately 400,000 audiograms of its personnel each year in its hearing conservation program; all these audiograms are traceable to NBS calibrations of microphones belonging to the primary standards laboratory of the service.

In each of the above examples, accuracy is considered a property of a measuring instrument such as a microphone or acoustic calibrator. The calibration of this instrument is traceable in an unbroken line of periodically performed measurements to calibration of the same or another instrument by the NBS.

Examples related to the second view of traceability include:

(i) Calibration laboratories or manufacturers who may have reciprocity calibration facilities of their own (but seldom, if ever, have either wide-band capability in conformance with the full ANSI S1.10 procedures, or a long record of interlaboratory comparisons) use NBS calibrations of their standard microphones performed at regular intervals to establish and to maintain the accuracy of their own facilities and procedures. If their own calibration results have been and continue to remain reasonably close to those of the NBS, they attain a degree of confidence that their own results are adequate, without expending large amounts of time and money in order independently to determine the influence of the previously cited acoustic and electroacoustic factors upon accuracy.

(ii) Laboratories or manufacturers may also use a continuing series of NBS-calibrated microphones to establish the approximate validity of their own non-standard microphone or other dynamic transducer calibration procedures, especially those (e.g., electrostatic actuators) suited to rapid and convenient repetitive testing of large quantities of instruments.

In these examples, continuing records of "traceability" to regularly performed NBS calibrations serve inexpensively to quantify measurement uncertainty and to give confidence in the quality of measurements made by a laboratory that may not have the time, staff, equipment, financial resources, or opportunity to validate either complex standard methods or simplified methods adequate for its purposes.

Whatever the view of traceability of acoustical instrument calibration that is employed, it can be argued that the value of a particular system for realizing traceability should be measured by its capacity to ensure measurements of adequate accuracy for their intended purpose.

The dominant sources of error in acoustic measurements are frequently attributable to uncertain acoustic characterization of the test environment, inadequate documentation or imperfect comprehension of measurement procedures, or carelessness. These errors may be one or two orders of magnitude larger than errors in microphone calibration. There is no substitute for careful, knowledgeable personnel with appropriate experience.

Special challenges exist for measurements for which no national standards or calibration services are available; e.g., measuring the peak level of impulsive sounds. Continued research in calibration methods to meet these challenges is essential.

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