FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

CALIBRATION: PRIMARY, SECONDARY, AND FIELD

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The primary calibration of acoustic and vibration transducers is well standardized and confirmed by round-robin interlaboratory test. Secondary calibration is also very common with traceability to primary calibration. Examples of set-ups for microphone and accelerometer secondary calibration are based on accuracy and frequency-response testing. Field check methods, using reference sources and other methods (like Phantom Calibration), are described, defining advantages and shortcomings.

1.0 INTRODUCTION

The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprised of all national electrotechnical committees (IEC National Committees). IEC's objective is to promote international cooperation on all questions concerning standardization in the electrical and electronic fields. Among other activities, the IEC publishes International Standards, the preparation for which is entrusted to technical committees. To promote international unification, IEC national committees try to apply the international standards transparently to the maximum extent possible in their national and regional standards. The IEC provides no marking procedure to indicate its approval and cannot be held responsible for any equipment declared to be in conformity with one of its standards. IEC 1094-2 specifies *Primary Method for Pressure Calibration of Laboratory Standard Microphones by the Reciprocity Technique*. IEC 1094-2 supersedes the earlier IEC recommendations 327 (1971) and 402 (1972).

2.0 PRINCIPLES OF PRESSURE CALIBRATION BY RECIPROCITY

A reciprocity calibration of microphones is carried out by means of three microphones, two of which are reciprocal. The reciprocity calibration method is an absolute method, based on fundamental or derived physical quantities. The basic measurement is U/I, where U is the open circuit voltage from the receiver microphone cartridge, and I is the current through the transmitter microphone cartridge when both are acoustically coupled to each other via a closed air volume. See Figure 1.

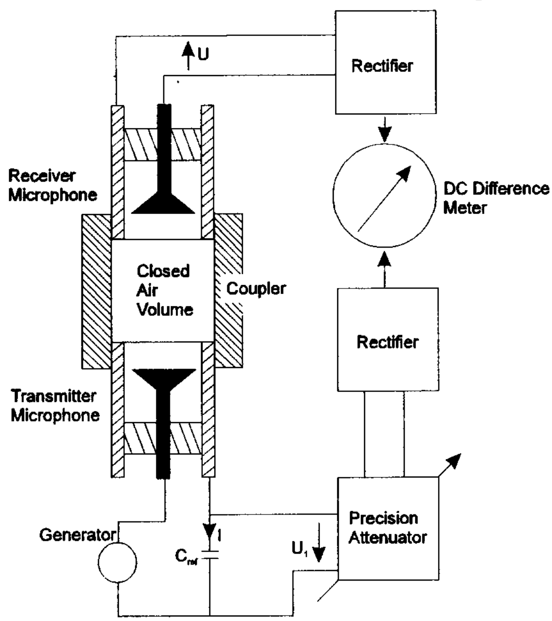

Figure 1. Principles of Pressure Calibration by Reciprocity

The current through the transmitter microphone cartridge is found by measuring the voltage (U_1) across a reference capacitor in series with the transmitter, which means that the frequency does not enter the calculations directly. By coupling the three microphones to each other, in turn, three sensitivity product values dB_{12}, dB_{13}, and dB_{23} are obtained. The dB_{12} is the sensitivity product value obtained with microphone No. 1 as transmitter and microphone No. 2 as the receiver.

The pressure sensitivity M_p of the microphones, in dB, ref. 1V/Pa can be calculated from the following equations (1):
(EQ 1)

$$M_{p1} = dB_{ref} - \frac{1}{2}(dB_{12} + dB_{13} - dB_{23})$$

$$M_{p2} = dB_{ref} - \frac{1}{2}(dB_{12} + dB_{23} - dB_{13})$$

$$M_{p3} = dB_{ref} - \frac{1}{2}(dB_{23} + dB_{13} - dB_{12})$$

The value of dB_{ref} is determined by the reference capacitor and the coupler used. The dB_{ref} should be corrected for static pressure and heat conduction. The basic calibration performed is that of the Reference Sensitivity, which is normally given at 250 Hz and at 1013 mbar. Any deviation in sensitivity of the microphone cartridge due to change in barometric pressure or change in temperature and at other frequencies is referred to the Reference Sensitivity.

When a calibration laboratory has traceability on fundamental and derived physical quantities related to the microphone reciprocity calibration measurement, that traceability is carried over to a microphone cartridge calibrated by the reciprocity method at the calibration laboratory. The reciprocity method is used by Standard Institutes for Calibration of Laboratory Standards. A small number of calibration laboratories have adopted the method for their own absolute calibration and maintain traceability to a given Standard Institute by a Transfer Standard. However, national and/or industry codes may require that the calibration laboratory use standard reference microphone cartridges calibrated by the National Standard Institute when calibrating measurement microphones.

3.0 COMPARISON CALIBRATION

An alternative method for calibrating the transfer, working standard reference microphone cartridges and measuring microphones is the comparison method using primary reference standards. The recommended procedure is the comparison by substitution calibration method, where the electronics are the same and the unknown microphone is compared to a standard calibrated in accordance with IEC 1094-2. The comparison by substitution method is preferred since the systematic errors caused by the electronics are canceled out.

4.0 OPEN CIRCUIT SENSITIVITY

The open circuit sensitivity "S" is the sensitivity of the microphone cartridge when it is electrically unloaded. It is normally corrected to the standard ambient pressure 1013 mbar. The open circuit sensitivity is obtained by the insert voltage method. The sensitivity is measured at 250 Hz. A pistonphone is used as the sound source. See Equation 2.

(EQ 2)

$$S_{1013} = S_{ref} + \left(\frac{S_{ref}(p_{amb})}{S_x(p_{amb})}\right)[dB] + \left(\frac{e_x}{e_{ref}}\right)[dB] + \left(\frac{V_x + V_{pist}}{V_{ref} + V_{pist}}\right)[dB] - \left(\frac{G_x}{G_{ref}}\right)[dB] - (D_{att.})[dB]$$

where:

[1] S_{ref}

is the sensitivity of the primary standard reference microphone cartridge at 1013 mbar, 23°C, 50% relative humidity.

[2] $\left(\frac{S_{ref}(p_{amb})}{S_x(p_{amb})}\right)[dB]$

is the ambient pressure correction factor for the type of microphone cartridge to be calibrated and the primary standard microphone cartridge.

[3] $\left(\frac{e_x}{e_{ref}}\right)[dB]$

is the obtained ratio, in dB, between the outputs of two microphone cartridges.

[4] $\left(\frac{V_x + V_{pist}}{V_{ref} + V_{pist}}\right)[dB]$

is the correction due to the deviation in loading volume between the microphone cartridge to be calibrated and the standard microphone cartridge.

[5] $\left(\frac{G_x}{G_{ref}}\right)[dB]$

is the correction for the deviation in overall gain (G) between the microphone cartridge to be calibrated and the standard microphone cartridge due to capacitive loading by the preamplifier.

[6] $$G = g + 20 \log_{10}\left(\frac{C_t}{C_t + C_i}\right) \text{ [dB]}$$

where: g = Preamplifier gain (dB)
C_t = Microphone capacitance (pF)
C_i = Preamplifier capacitance (pF)

[7] $$(D_{att}) \text{ [dB]}$$

is the attenuator setting (precision attenuator).

To assure that the calibration system has sufficient precision and to verify that conditions exist to perform the calibration to the required accuracy, a calibration system verification is performed. This is done by selecting one primary standard microphone cartridge as the reference, then calibrating the reference sensitivity of a second reference standard microphone cartridge. The obtained value is compared to the given value on the calibration certificate. If the value is within a given tolerance (0.03 dB), the transfer or working standard and/or measurement microphone can be calibrated. Traceability is maintained through the primary standard. The total uncertainty of the comparison calibration is 0.09 dB at a 99% confidence level, which is about twice the estimated uncertainty for the reciprocity calibration method.

5.0 CONDENSER MICROPHONES, FREQUENCY RESPONSE

IEC 1094-3: 199X, *Primary Method for Free-Field Calibration of Laboratory Standard Microphones by the Reciprocity Technique*, governs the calibration of the condenser microphone's free-field response. An alternative way of calibrating the frequency response of the condenser microphone is the electrostatic actuator method. A plane electrode is placed parallel to the diaphragm at a distance of approximately 0.5 mm. Polarization voltage of 800 VDC, with 100 volts RMS AC excitation voltage should be applied, producing an electrostatic pressure of approximately 104 dB. A signal with twice the excitation frequency is also produced. The amplitude of this signal is less than 5% of the fundamental signal and can increase the RMS level 0.01 dB if the condenser microphone sensitivity is the same for both frequencies. This method cannot be used below 20 Hz. Calibration at low frequencies demands a special low-frequency calibrator.

For free-field types of microphones, a "free-field correction" is added to the obtained actuator response, yielding the free-field response of the microphone. Pressure-type condenser microphones require a "random incidence correction" to be added to the actuator response. Both the free-field and random incidence corrections can be outlined as a curve versus frequency or in table form. The uncertainty of these methods has been reported by others.

6.0 FIELD CHECK

Over the past two to three years, new methods for in-situ checking of vibration and acoustic sensors have been introduced. Today, a convenient, simplified system is available that permits in-situ check of accelerometer functionality and mounting performance. For condenser microphones, the "Phantom Calibration" makes easy the verification of the integrity of the microphone system before starting a measurement and is an excellent way to verify a multi-channel configuration in a short time. It is preferable to a past method, wherein each channel was checked using a portable calibrator. In many cases, the microphone tested is more stable than the portable calibrator. For condenser measurement microphones, a single-point check gives good confidence in the measuring system since the sensitivity cannot change without alteration in the frequency; however, for accelerometers, the single-point check is no guarantee that the sensor fulfills its specification. It is merely a verification that the gain settings in the measurement chain are correct.

There are a number of ways to verify the vibration and the acoustic measuring systems, but the aforementioned methods, mounted resonance check and phantom calibration, are faster and more accurate. Reference sources may also be used, provided that the reference has better stability than the device to be checked. A pistonphone, for example, is one of the most reliable and accurate calibration references available, although it is time-consuming by comparison.

7.0 CONCLUSION

The primary calibration of precision measurement microphones is well standardized and confirmed by round-robin interlaboratory test. Secondary calibration, using the comparison by substitution method, is becoming more commonplace in local recalibrations. Accurate calibration of precision measurement microphones requires persons who pay close attention to details and correctly follow procedures. There are numerous places throughout the calibration process that require this scrupulous attention, such as maintaining the cleanliness of the adapter surfaces. Without careful personnel, achieving the accuracy required is nearly impossible.

REFERENCES

IEC Standard 1094-2, *Primary Method for Pressure Calibration of Laboratory Standard Microphones by the Reciprocity Technique.*

Schonthal, Ernst, *Methods for Calibration of Acoustic Measurement Reference Standard*, Brüel and Kjær, Marlborough, MA.