Setting up of Acoustic Standards and Calibration Facility at SCL

Speaker/Author: Aaron Y.K. Yan
Standards and Calibration Laboratory (SCL)
36/F., Immigration Tower, 7 Gloucester Road, Wanchai, Hong Kong
Phone: (852) 2829 4855, Fax: (852) 2824 1302, Email: ykyan@itc.gov.hk

Abstract

The Government of The Hong Kong Special Administrative Region Standard and Calibration Laboratory (SCL) is the primary standards laboratory for Hong Kong. SCL has recently set up standards and calibration facility for acoustic measurements. The facility includes a primary calibration system for laboratory standard microphones and calibration systems for working microphones, sound calibrators and sound level meters. The laboratory has participated in a recent Asia Pacific Metrology Programme (APMP) key comparison on LS1P laboratory standard microphones APMP.AUV.A-K1. The preliminary comparison results showed that SCL's results agreed well with the comparison's reference values. For future development, SCL is in the process of developing new acoustic calibration services for audiometers and ear simulators.

1. Introduction

Sound is a common phenomenon that occurs in our everyday life. However, only until recently, precision measurement of sound can be made with the use of modern electro-acoustic equipment.

1.1 Units of acoustic measurements

The basic unit of sound measurement is the sound pressure, measured in unit of pascal (Pa). A related unit, sound pressure level (SPL), is defined as the logarithmic ratio of pressure with a reference pressure of 20 μPa.

$$SPL = 20\log\left(\frac{P}{P_r}\right)$$

where Pr = 20 μPa

Other units of acoustic measurements are derived from the unit of sound pressure.

1.2 Traceability of acoustic measurements

The traceability chart of acoustic measurements is shown in Figure 1. The reference standard for sound measurements is the laboratory standard microphone, through which the sound pressure is defined. Working grade microphones, used as secondary and working standards, are calibrated by comparison with the laboratory standard microphones. Sound calibrators, used to generate known sound pressure levels, are in turn calibrated by working microphones. Sound level meters, the most commonly used equipment for everyday sound measurements, are calibrated using the sound calibrators and other electrical measuring instruments.

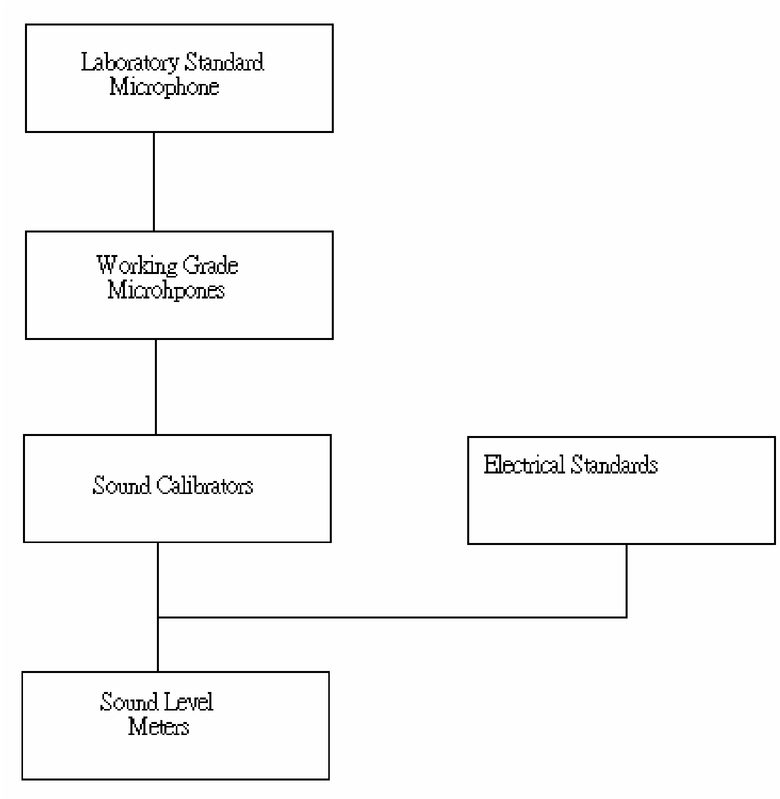

Figure 1 – Traceability system for acoustic measurements.

2. Calibration System for Laboratory Standard Microphones

The calibration system for laboratory standard microphones [1] is based on the primary calibration method of reciprocity as described in International Standard IEC 61094-2 [2].

2.1 Theory of measurement

Laboratory standard microphones are reciprocal transducers that can be operated either as transmitters or receivers. The sensitivities of these microphones when they are operated either as transmitters or receivers are identical. Making use of this property, laboratory standard microphones are calibrated using reciprocity technique. The technique requires the used of three microphones A, B and C. Three measurements are made. For each measurement, two microphones are used. The two microphones are connected acoustically by a coupler. One microphone is acted as a transmitter and the other microphone is acted as a receiver. The electrical transfer impedance (the ratio between the voltage of the receiving microphone and the current of the transmitting microphone) is measured. From known value of acoustic impedances of the system, the product of the pressure sensitivities of the two microphones is determined.

$$M_A \cdot M_B = \frac{Z_{e,AB}}{Z_{a,AB}} \quad \text{------------------- (1)}$$

$$M_B \cdot M_C = \frac{Z_{e,BC}}{Z_{a,BC}} \quad \text{---------------------(2)}$$

$$M_C \cdot M_A = \frac{Z_{e,CA}}{Z_{a,CA}} \quad \text{---------------------(3)}$$

where

M_A, M_B and M_C are the sensitivities of the microphones A, B and C respectively

$Z_{e,XY}$ are the electrical transfer impedance of microphone pair X and Y

$Z_{a,XY}$ are the acoustic transfer impedance of microphone pair X and Y

At lower frequencies, the acoustic transfer impedance is affected by heat conduction process that occurs at the surface of the coupler. At higher frequencies, the dimension of the coupler approaches the wavelength of the acoustic signal and therefore the wave motion effect becomes prominent. Taking into account the high and low frequency effects, the acoustic transfer impedance becomes:

$$\frac{1}{Z_{a,XY}} = \frac{1}{Z_{a,0}}\left[\left(\frac{Z_{a,0}}{Z_{a,X}} + \frac{Z_{a,0}}{Z_{a,Y}}\right)\cosh(\gamma \cdot l_{XY}) + \left(1 + \frac{Z_{a,0}}{Z_{a,X}} + \frac{Z_{a,0}}{Z_{a,Y}}\right)\sinh(\gamma \cdot l_{XY})\right]\Delta H_{xy}$$

where

$Z_{a,0}$ is the acoustic impedance of the coupler

$Z_{a,X}$ and $Z_{a,Y}$ are the acoustic impedances of the diaphragms of microphones X and Y

γ is the complex propagation coefficient

l_{XY} is the coupler cavity length

ΔH_{xy} is the correction for heat conduction effect

The three pressure sensitivities (M_A, M_B and M_C) are obtained by solving the three simultaneous equations (1), (2) and (3).

2.2 System components

The pressure reciprocity calibration system comprises the following components:

- a PC for computer control

- a microphone fixture for mounting the microphones
- coupler for reciprocity measurement
- preamplifiers for the transmitting and receiving microphones
- switching unit for insert voltage measurement
- a bandpass filter
- digital multimeters
- software for controlling the measurement process and calculating the open circuit pressure sensitivities

Figure 2 - Reciprocity calibration system for laboratory standard microphones.

2.3 Measurement ranges and uncertainties

The system is capable of calibrating one-inch laboratory standard microphones (LS1P) from 63 Hz to 10 kHz and half-inch laboratory standard microphones (LS2P) from 63 Hz to 25 kHz. The measurement uncertainty at a level of confidence of 95 % ranges from 0.04 dB to 0.14 dB.

3. Calibration System for Working Standard Microphones

The calibration system for working microphones [3] is based on the method of comparison in a coupler as described in International Standard IEC 61094-5 [4].

3.1 Theory of measurement

The sensitivity of the working microphones is determined by comparison with a reference microphone in a coupler. Both the test microphone and the reference microphone are exposed to a uniform sound filed in a coupler. The sound pressure in the coupler can be determined by measuring the output voltage of the reference microphone using insert voltage method. The pressure sensitivity of the test microphone can then be determined by measuring the output voltage of the test microphones also using insert voltage method.

$$P = \frac{V_1}{M_{1,t}}$$

$$P = \frac{V_2}{M_{2,t}}$$

$$\frac{V_1}{M_{1,t}} = \frac{V_2}{M_{2,t}}$$

Therefore

$$M_{2,t} = M_{1,t}\left(\frac{V_2}{V_1}\right) \text{ ---------------------------(4)}$$

where

P is the sound pressure in the coupler

$M_{1,t}$ and $M_{2,t}$ are the open circuit pressure sensitivities of the reference and test microphones at test conditions respectively

V_1 and V_2 are the open circuit voltages of the reference and test microphones respectively, measured using insert voltage method.

The reference microphone is calibrated at reference conditions (23 °C, 101.325 kPa and 50 % RH) , corrections for the temperature, pressure and humidity effects for the reference microphone should be applied. The pressure sensitivity of the reference microphone at test conditions is:

$$M_{1,t} = M_{1,r}\left[1+\alpha_{t,1}(t-t_r)\right]\left[1+\alpha_{h,1}(h-h_r)\right]\left[1+\alpha_{p,1}(p-p_r)\right]$$

$$M_{2,t} = M_{1,r}\left[1+\alpha_{t,1}(t-t_r)\right]\left[1+\alpha_{h,1}(h-h_r)\right]\left[1+\alpha_{p,1}(p-p_r)\right]\left(\frac{V_2}{V_1}\right) \text{------------- (5)}$$

The pressure sensitivity of the test microphone is normally reported with corrected to the reference conditions (23 °C, 101.325 kPa and 50 % RH) is:

$$M_{2,r} = M_{2,t}\left[1+\alpha_{t,2}(t_r - t)\right]\left[1+\alpha_{h,2}(h_r - h)\right]\left[1+\alpha_{p,2}(p_r - p)\right] \text{ -------------(6)}$$

Substitute (5) and (6) into (4), we get

$$M_{2,r} = \frac{V_2}{V_1} M_{1,r}\left[1+\alpha_{t,1}(t-t_r)\right]\left[1+\alpha_{h,1}(h-h_r)\right]\left[1+\alpha_{p,1}(p-p_r)\right]\left[1+\alpha_{t,2}(t_r - t)\right]\left[1+\alpha_{h,2}(h_r - h)\right]\left[1+\alpha_{p,2}(p_r - p)\right]$$

where

$M_{1,r}$ and $M_{2,r}$ are the open circuit pressure sensitivities of the reference and test microphones at reference conditions

$\alpha_{t,1}$ and $\alpha_{t,2}$ are the temperature coefficients of the reference and test microphones respectively.

$\alpha_{h,1}$ and $\alpha_{h,2}$ are the humidity coefficients of the reference and test microphones respectively.

$\alpha_{p,1}$ and $\alpha_{p,2}$ are the pressure coefficients of the reference and test microphones respectively.

t and t_r are the temperature at test and reference conditions respectively

h and h_r are the humidity at test and reference conditions respectively

p and p_r are the pressure at test and reference conditions respectively

3.2 System components

The calibration system for working microphones comprises the following components:

- a PC for computer control
- a microphone fixture for mounting the microphones
- coupler for comparison measurement
- preamplifiers for the test and reference microphones
- switching unit for insert voltage measurement
- two digital multimeters
- software for controlling the measurement process and calculating the open circuit pressure sensitivities

3.3 Measurement ranges and uncertainties

The system is capable of calibrating half-inch (WS2P) working grade microphones from 63 Hz to 20 kHz. The measurement uncertainty at a confidence level of 95 % ranges from 0.07 dB to 0.20 dB.

Figure 3 - Calibration system for working grade microphones.

4. Calibration System for Sound Calibrators

The calibration system for sound calibrators makes use of a calibrated laboratory standard microphone to measure the sound pressure level of a sound calibrator in accordance with International Standard IEC 60942 [5].

4.1 Theory of measurement

The sound pressure level of a sound calibrator is determined by measuring the output voltage of a reference microphone using insert voltage method.

$$P = \frac{V_1}{M_{1,t}}$$

where

P is the sound pressure in the coupler of the sound calibrator

$M_{1,t}$ is the open circuit pressure sensitivities of the reference microphone at test conditions

V_1 is the open circuit voltage of the reference microphone, measured using insert voltage method.

The reference microphone is calibrated at reference conditions (23 °C, 101.325 kPa and 50 % RH) , corrections for the temperature, pressure and humidity effects for the reference microphone should be applied. The pressure sensitivity of the reference microphone at test conditions is:

$$M_{1,t} = M_{1,r}\left[1+\alpha_{t,1}(t-t_r)\right]\left[1+\alpha_{h,1}(h-h_r)\right]\left[1+\alpha_{p,1}(p-p_r)\right]$$

$$P = \frac{V_1}{M_{1,r}\left[1+\alpha_{t,1}(t-t_r)\right]\left[1+\alpha_{h,1}(h-h_r)\right]\left[1+\alpha_{p,1}(p-p_r)\right]}$$

The sound pressure level of the sound calibrator is normally reported at reference conditions (23 °C, 101.325 kPa and 50 % RH). Sound pressure level at reference conditions Pr with corrections for the temperature, humidity and pressure effects is:

$$P_r = P\left[1+\alpha_{t,2}(t_r-t)\right]\left[1+\alpha_{h,2}(h_r-h)\right]\left[1+\alpha_{p,2}(p_r-p)\right]$$

$$P_r = \frac{V_1\left[1+\alpha_{t,2}(t_r-t)\right]\left[1+\alpha_{h,2}(h_r-h)\right]\left[1+\alpha_{p,2}(p_r-p)\right]}{M_{1,r}\left[1+\alpha_{t,1}(t-t_r)\right]\left[1+\alpha_{h,1}(h-h_r)\right]\left[1+\alpha_{p,1}(p-p_r)\right]}$$

where

$M_{1,r}$ is the open circuit pressure sensitivity of the reference microphone at reference conditions

$\alpha_{t,1}$ and $\alpha_{t,2}$ are the temperature coefficients of the reference microphone and the sound calibrator respectively.

$\alpha_{h,1}$ and $\alpha_{h,2}$ are the humidity coefficients of the reference microphone and sound calibrator respectively.

$\alpha_{p,1}$ and $\alpha_{p,2}$ are the pressure coefficients of the reference microphone and sound calibrator respectively.

t and t_r are the temperature at test and reference conditions respectively

h and h_r are the humidity at test and reference conditions respectively

p and p_r are the pressure at test and reference conditions respectively

4.2 System components

The calibration system for sound calibrators comprises the following components:

- a PC for computer control
- a microphone fixture for mounting the reference microphone
- preamplifier for the reference microphone
- switching unit for insert voltage measurement
- a digital multimeter
- software for controlling the measurement process and calculating the sound pressure level

Figure 4 Calibration System for Sound Calibrators

4.3 Measurement ranges and uncertainties

The system is capable of measuring the sound pressure level of sound calibrator from 63 Hz to 16 kHz. The measurement uncertainty at a confidence level of 95 % ranges from 0.06 dB to 0.09 dB.

5. Calibration System for Sound Level Meters

Sound level meters are calibrated in accordance with International Standards IEC60651 [6] and IEC 60804 [7]. Recently, these standards have been replaced by new IEC standards IEC61672-1 [8] and IEC61672-2 [9].

5.1 Test preformed

For a complete calibration of sound level meters, the following electrical and acoustic tests are performed:

(A) Electrical

- Linearity range test
- Frequency weighting A, C and Linear tests

- Overload test
- Level range control test
- RMS detector test
- Time weighting Fast, Slow and Impulse tests
- Time averaging test
- Pulse range test
- Self-generated noise test

(B) Acoustical

- Acoustical response test

5.2 Theory of measurement

Acoustical response tests are performed using a sound calibrator. The microphone of the sound level meter is coupled to a sound calibrator. The response of the sound level meter is compared with the known pressure level of the sound calibrator.

For electrical tests, the microphone of the sound level meter is replaced by an equivalent capacitance. Electrical signals are applied through the equivalent capacitance. For the following tests, steady sinusoidal signal is applied:

- Linearity range test
- Frequency weighting A, C and Linear tests
- Overload test
- Level range control test
- Self-generated noise test

For tests listed below, tone burst signal is applied:

- RMS detector test
- Time weighting Fast, Slow and Impulse tests
- Time averaging test
- Pulse range test

The response of the sound level meter to the applied signal is recorded and compared with the calculated response with the applied tone burst parameters.

5.3 System components

The calibration system for working microphones comprises the following components:

- a PC for computer control
- a signal generator capable of generating sinusoidal signal as well as tone burst signal.

- a sound calibrator
- software for controlling the measurement process

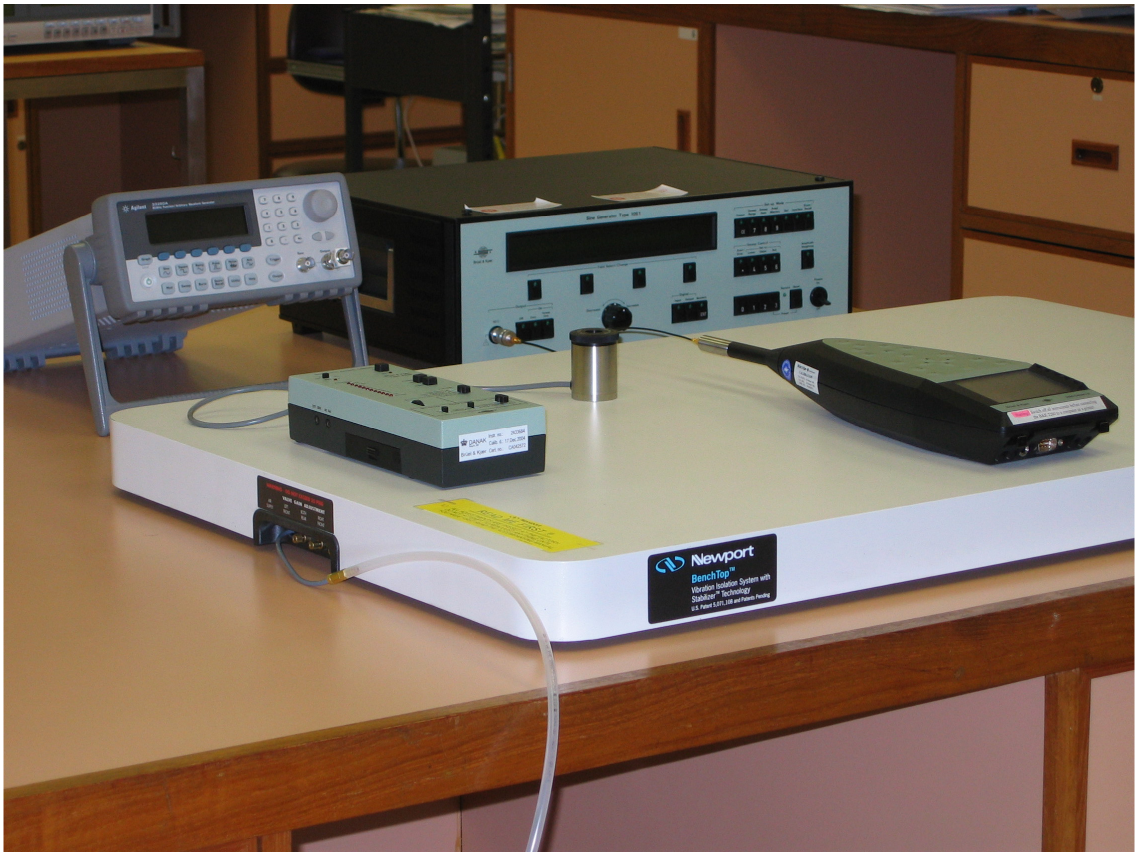

Figure 5 – Calibration System for Sound Level Meters

6. Key Comparison

SCL has participated in a recent Asia Pacific Metrology Programme (APMP) key comparison on LS2P laboratory standard microphones APMP.AUV.A-K1. The comparison made use of a one-inch condenser microphone circulated around the participants. Each participant determined the open circuit pressure sensitivity of the microphones at the reference environmental conditions. The preliminary comparison results showed that SCL's results agreed well with the comparison's reference values.

7. Future Development

SCL is planning to set up standards and calibration facility for audiometers and ear simulators to support the medical laboratories and telecommunication testing laboratories in Hong Kong. We have acquired the equipment for setting up such service and are testing the calibration methods. The new services will be available in the middle of 2007.

References

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