

Measurement of Bone Conduction Levels for High Frequencies

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Abstract

For assessment of safety, it is necessary to measure the maximum force that a bone conduction device coupled to the head is capable of exerting. Calibration of bone conduction hearing aids and vibrators in the audiometric range is based on measurement of acceleration and force using an artificial mastoid, but the range is limited to 10 kHz. We describe here a method for extending measurement to the high audio range, and discuss the issues in regard to the ultrasonic range. To assess safety in the UltraQuiet™ tinnitus treatment system, we measured acceleration from 5 to 20 kHz on a live human head, in comparison with standard audiometric levels at 6 kHz from a Radioear B-71 vibrator on the artificial mastoid and the live head.

Keywords: tinnitus, UltraQuiet™, high frequency hearing thresholds

Introduction

For assessment of safety, it is necessary to measure the maximum force that a bone conduction device coupled to the head is capable of exerting. The force exerted by bone conduction vibrators in audiometry and its relation to hearing level is normally measured according to standard ANSI S3.43-1992, for frequencies up to 4 kHz. The UltraQuiet™ is a tinnitus therapy device that uses bone conducted vibration up to 20 kHz [1]. There is no standard for calibration of bone conduction force in the UltraQuiet™ range from 6 kHz to 20 kHz. There are also no artificial mastoids with impedance calibrated in this range (e.g., the B& K 4930 is calibrated to 10 kHz). Here we measure the UltraQuiet™ system on a live human head to 20 kHz and on a B&K 4930 artificial mastoid to 10 kHz, in comparison with standard audiometric levels at 6 kHz from a Radioear B-71 vibrator on the artificial mastoid and the live head [2].

Methods

The measurement system consisted of a Brüel & Kjaer 4374 accelerometer with a Brüel & Kjaer Pulse 3560 analysis system. As reference levels for our calibration, we used a Radioear B-71 bone vibrator with its standard headband as the static force (measured at 4.4 N) compared to a plastic headband with a static force of 1.5 N and an Interacoustics AC40 audiometer, at 0 dB HL and 55 dB HL, on a live human head, since no artificial mastoids are calibrated in the higher frequency range. There was no difference between the two headbands; with complete coupling, the difference in static force made no difference in the measured acceleration.

Measurements were made by placing the B&K accelerometer between the transducer (either the Radioear B-71 or the UltraQuiet™ piezoelectric) and the head, with the accelerometer/transducer combination held in place with the headband.

Although the standard is given in force, measurements are often made in acceleration for practical reasons, and converted to force [3]. Hakansson et al., in their calibration of direct bone conduction, faced a similar need to extrapolate from existing standards.

The formula for calculation of force is $F = |Z| \times A/\dot{\omega}$, where:

F = force in N

A = acceleration in m/s^2

|Z| = mechanical point impedance in Ns/m

$\dot{\omega}$ = angular frequency (radians/s)

Using the above equation, the following numbers apply to 6 kHz, taken from Table 1 in Hakansson et al. [3], based on the Reference Equivalent Threshold Force Levels (RETFL) as proposed in ISO/DIS 7566, and the mechanical impedance of the head at the skin surface in the draft revision of IEC publication 373, 1971.

Frequency:	6000 Hz
RETFL (dB re 1 μ N):	40.0 dB
Mechanical Impedance (dB re 1 Ns/m):	34.0 dB
RETAL (dB acceleration re 1 cm/s^2):	17.5 dB (-2.5 dB re 1 m/s^2)

Results

Five UltraQuiet™ systems were measured. The maximum output of the loudest of the five UltraQuiet™ systems at 6 kHz was 30 dB of acceleration, or 70 dB of force re 1 μ N. This is equivalent to 42.5 dB HL, or roughly equivalent to 58.0 dB SPL at 6 kHz (rough SPL estimate based on addition of 15.5 dB conversion factor for SPL to HL for TDH-49

audiometric headphones). Figure 1 shows the average acceleration response of five systems through the 6 to 20 kHz frequency range, using random noise. The average at 6.0 kHz was 27.0 dB of acceleration, or 67.0 dB of force, equivalent to 39.5 dB HL

Based on the above table, using an artificial mastoid, at 0 dB HL and 6 kHz, the force should be 40.0 dB and the acceleration should be -2.5 dB. In our experimental arrangement, the acceleration was -12.5 dB re 1 m/s^2 . Thus a correction factor of 10.0 dB must be added to our data to yield measurements comparable to the standard. This is similar to the method used by Hakansson et al. to arrive at correction factors for direct bone conduction via a screw attached to the skull [3].

In the same experimental arrangement, the 55 dB HL signal from the audiometer produced a 42.0 dB re 1 m/s^2 acceleration (54.5 dB more than the -12.5 dB acceleration at 0 dB HL), confirming the linearity of the system within 0.5 dB.

Discussion

Safety is always a concern in delivering high frequencies to human listeners. Figure 2 shows the average bone conduction thresholds in water measured by Corso, compared to the range and maximum output of the UltraQuiet™ at 6 kHz [4]. This is the frequency where hearing would normally be most sensitive within the range of the UltraQuiet™, and at which the threshold would be determined to set the listening level. At the recommended listening level (12 dB SL) for UltraQuiet™, the high frequency cut off would be about 15 kHz and highest listening level possible, the high frequency cutoff would be about 18 kHz. Note for a person with normal hearing there is a 60 dB increase in threshold over the octave of 10 to 20 kHz. Thus the steep rise in human hearing thresholds plus the digital sampling rate (44.1 kHz) and antialiasing filtering limitations insures safe usage of devices like UltraQuiet™.

There is no such steep threshold rise with audible ultrasonic frequencies (17.5 dB/octave from 20-80 kHz); further thresholds for ultrasonic frequencies (25-55 kHz) are some 75-90 dB above that at 6 kHz. Thus ultrasonic stimulation involves much higher intensity and consequently more concern for damage risk than high audio frequencies. Deatherage et al, [5] working with a water coupled 50 kHz tone reported thresholds comparable to Corso (after conversion of reference value) and high frequency hearing loss plus persistent tinnitus due to exposure with above threshold loudness judgments. The current OSHA standard sets a value of 1 g rms +15 dB at the mastoid as a level not to be exceeded to avoid risk if there is direct ultrasonic coupling to the body with simultaneous airborne exposure. This level is conservative, however tones 30 dB above threshold at any ultrasonic frequency are reported to be loud and unpleasant [6] and damage risk data are lacking. Clearly there may be little room for a safety margin with normal hearing and hearing impaired ultrasonic listeners [7]. Ultrasonic standards for bone conduction hearing are needed to assess risk.

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Figure Legends

Figure 1. Comparison of the frequency response on the B&K 4930 artificial mastoid and the live head of the UltraQuiet™ system (average of measurement of 5 systems); reference calibration at 6 kHz at 0 dB and 55 dB HL with Radioear B-71 vibrator.

Figure 2. Hearing thresholds in water (dB SPL) from Corso (1963) compared with range and maximum output of the UltraQuiet™ at the frequency in its output range of greatest intensity and most sensitive hearing (6 kHz).

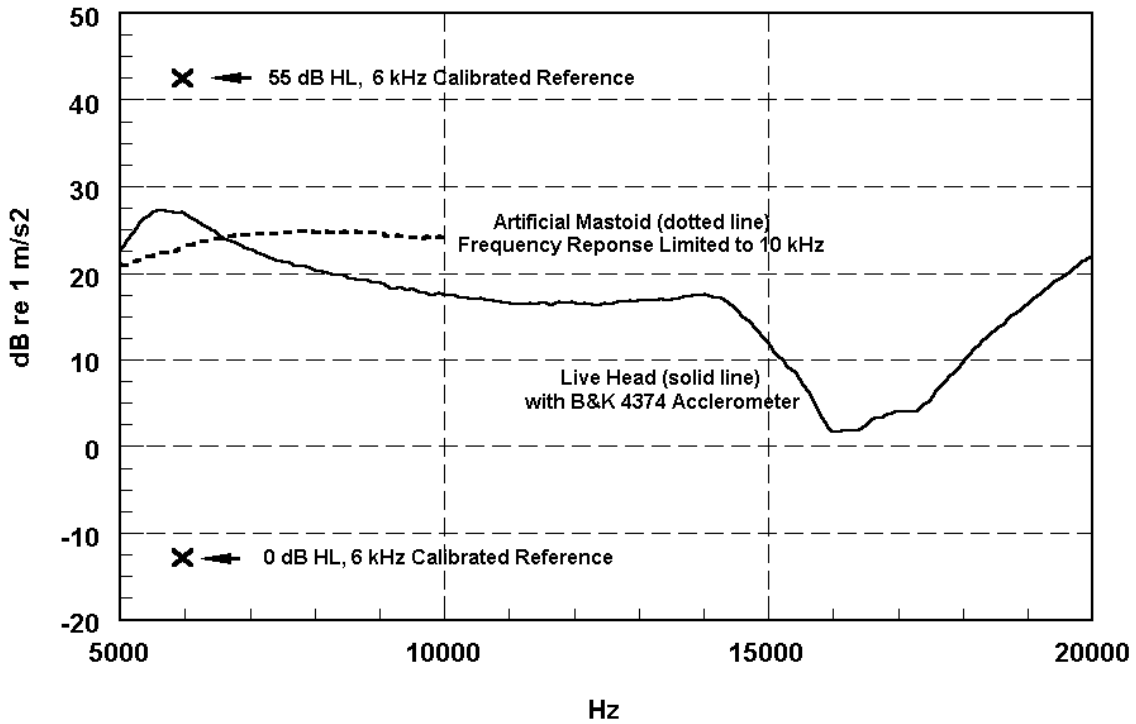


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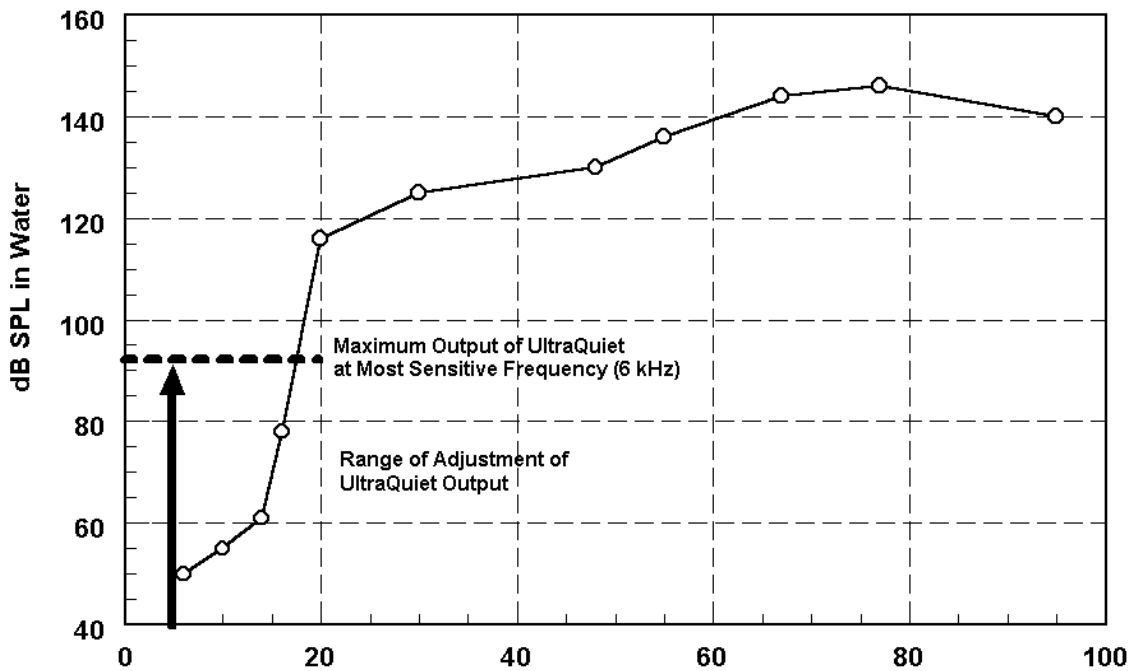


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